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THE DISTRIBUTION OF SUMMER SHOWERS OVER A SMALL AREA

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ABSTRACT

The scatter of summer showers in both time and space over the southeastern States is such that the distribution of synoptic weather reporting does not permit an accurate appraisal of the distribution of rainfall. The objectives of this investigation are to determine (1) the density of the reporting network that would be necessary to describe the areal coverage of rainfall in a given locality, and (2) the relation between this areal coverage and the average amount of rain. The localities chosen for study are Birmingham, Ala. and Atlanta, Ga., and the areas representative of these localities are defined as circles of about 50-mile radius around the Birmingham and Atlanta airports. Precipitation data used to determine the areal distribution were taken from 37 cooperative stations plus 3 first-order reporting stations in each of these areas. An analysis of these data shows, for most purposes at least, that this distribution of 40 stations provides a good indication of the precipitation coverage, and further, that an observation from one station or even the 3 first-order stations is not representative of the areal coverage. A close relationship is found between the average amount of rain per station and the areal coverage.

INTRODUCTION

Rainfall over the Southeastern States during the summer season occurs most of the time in the form of scattered or isolated showers. Some interests, such as flood control units, agricultural departments, or marketing agencies are interested in the areal coverage, whereas individual farmers are more concerned with the probability of rain occurrence. The verification of rain occurrence during this season is rather complicated if the purpose is to distinguish between days on which showers occur and those on which no showers occur. Obviously, one point of observation is not enough on which to base the distinction, because of the scatter of showers in time and space. As several questions regarding shower distribution arose during the development of an objective aid in forecasting summer rain in the Birmingham, Ala. area, it became necessary to develop some data on the subject before proceeding with the original study. The purpose of this note is to report some of the data which may be of general interest.

Specifically, three studies were made to determine: (1) the frequency of rain days in the Birmingham area, (2) the frequency of occurrence of rain at a given maximum number of stations, and (3) the relation between the areal coverage and the average amount from the stations reporting rain on any particular day.

SELECTION OF AREA AND DATA

The question of how large an area and how numerous the observation points within this area must be in order to accurately verify forecasts for the Birmingham area cannot be simply and easily answered. Some information is available concerning the average rainfall amounts over an area as determined by various spacings of the rain gages [1 and 2], but the question of rain occurrence is quite a different one and remains unsolved. The magnitude of the errors of sampling is a function of the number of measurements, which in this case may be either in time or space. Data available to determine the optimum size of the area, or the density of reporting stations within this area, are limited so that some compromise must be made initially to decrease either the period of record or the number of reporting stations available for this study. Since convective showers ordinarily move with the prevailing winds during their life cycle, considerably fewer stations would be required to determine the areal distribution of rain or no-rain over a relatively small area, disregarding the exact time of occurrence during a particular day, than to ascertain the maximum amount of rainfall near the individual storm centers. The principal interest here was in the distribution of summer showers within a circle of radius about 50 miles around the Birmingham airport, arbitrarily selected to define the Birmingham area.

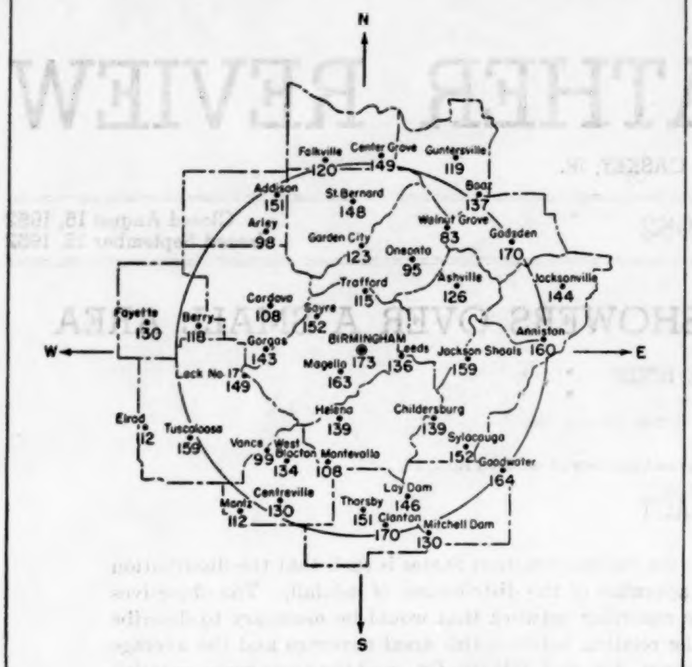

FIGURE 1.—Map showing the location of stations in the Birmingham, Ala. area and the total number of rain days for each station during the 5 summer seasons (June, July, August), 1946–1950.

After thus laying out the Birmingham vicinity, or area, all of the various stations reporting precipitation within this area which were listed in the Climatological Data [3] were examined for completeness of record during the summer season, June, July, and August. It was found that 40 stations could be utilized which had complete, or nearly complete, records during a 5-year period, 1946 through 1950, and which also reported the 24-hour precipitation amounts ending around 0700 EST, or hourly amounts so that they could be adjusted to this time. The frequency distribution of either hourly rainfall amounts or hourly occurrences for this area and season shows a very decided maximum during the afternoon and evening and with the minimum early in the morning. Since the concern is with shower days rather than the time of occurrence during the day, the period was ended nearest the time of minimum occurrence. Also, the geographic location of these reporting stations was considered in making the selection so that the stations were rather evenly distributed over the area. (See fig. 1.) Of the 40 stations used, there were four stations with six months of data missing and nearby stations which were not included among the 40 were substituted for five of these six months. There was a total of 37 dates with data from one station missing and on one date the data for three stations were missing, but in no case could incomplete data have resulted in all 40 stations reporting rain.

For the purposes of this study, the frequency of summer showers is assumed to be uniform over the area, even though full justification of this is not provided by the data, as will be shown in the next paragraph. However, the assumption is implicit in the phrasing of forecasts for this region. Most forecasters in the Southeast feel that they cannot usually predict, for a particular day, that one section of an area of this size will get rain and that an adjacent section will not. Thus the forecaster must phrase his prediction in terms of areal coverage and, if a random distribution over the area can be assumed, this amounts to a probability statement of occurrence for any particular location. It should be expected that the topographic features of the various station locations, even in an area of this relatively small size, would lead to at least small differences in the frequency of shower occurrence, but these differences are generally assumed to be unimportant.

The total number of rain days during summer over the 5-year period for each station is shown in figure 1. These data suggest that either the distribution is not entirely uniform, or that the period of record is too short. For example, Gadsen reported more than twice the number of rain days that were reported at Walnut Grove some 15 miles away. But for the most part, the differences in the total number of shower days between adjacent stations or different sections of this area did not seem unduly large. For several reasons, data on the time of occurrence of rain at some of these cooperative stations are not entirely dependable. A further check on the distribution is available through data at nearby First-Order Weather Bureau stations. The mean number of days with measurable rain was found for Montgomery, Ala., Birmingham, Ala., Chattanooga, Tenn., Atlanta, Ga., Macon, Ga., and Augusta, Ga. The length of record here varied between 52 and 80 years and these data showed no significant differences between stations. Therefore it is assumed for purposes of this study that the frequency of summer showers in this area is uniform over the area.

RESULTS FOR THE BIRMINGHAM AREA

Climatological data show that rain occurs on from 18 to 38 percent of summer days at individual stations in the Birmingham area. If the showers are randomly distributed, the occurrence of rain at one station is not indicative of showers at other stations except that the probability increases in proportion to the number of shower occurrences within the area. The relation between the percentage of rain days in the Birmingham area and the number of reporting stations within this area used in determining this percentage is shown in figure 2. The term "rain day" as employed here refers to a day in which measurable rain was reported by at least one of the stations within the group being considered. By using a single station, Birmingham airport, it was found that rain occurred on about 38 percent of the days. This compares with about 37 percent for a 55-year record. Increasing the station density to include 5 stations (Birmingham plus

one from each quadrant) it was found that rain occurred at at least one of these stations on 54 percent of all days. The station density was next increased to include these 5 stations plus 5 more, and then repeated for 20 stations, 30 stations, and finally for all 40 stations. These data were entered on figure 2 and a smooth curve fitted by eye. Although the extrapolation to higher station density is rather uncertain, it is believed that there are a few days during each summer season when no rain would occur over this area, so it is reasonable to assume that this curve would not reach 100 percent regardless of the density of reporting stations. If it were possible to double or triple this number of stations (40), the number of rain days would probably increase only slightly. Indeed, the curve drawn in figure 2 suggests that data from even 30 stations would, for some purposes, adequately describe the occurrence or non-occurrence of rain days in this area. It therefore seems reasonable to conclude, at least tentatively, that this distribution of 40 stations gives a fairly good indication of the precipitation coverage, and further, that an observation from one station is not representative of whether or not showers have occurred in the area.

If it is assumed that the occurrence of rain days is adequately determined through the use of data from these 40 stations, some interesting information is available on the expected probability of occurrence of rain at a particular station. Figure 3 shows the percentage of summer days when the total number of stations reporting rain was not greater than that shown. For example, on 38 percent of all summer days during this 5-year period, the maximum number of stations reporting rain was 3 so that on 38 percent of these days no more than three stations, and usually less, actually reported rain. In this case no station reported rain on 18 percent of the days, one station reported rain on 9 percent of the days, two stations reported rain on 6 percent of the days, and three stations reported rain on 5 percent of the days, making a total of 38 percent of the days when three stations, or less, reported rain. Thus, with a perfect forecast of the percentage of areal coverage of rain, the forecaster could be certain of a correct forecast for a particular station only on those occasions when either all or none of the area would receive rain. All stations reported no rain on 18 percent of the days while all stations reported rain on less than 1 percent of all days. Considering all cases, the probability of occurrence of no-rain at a station is less than 50 percent on about 75 percent of the days while on the remaining 25 percent of the days, the probability of rain is 50 percent or greater.

It would be desirable to have further information regarding the relation between the occurrence of rain and the average amounts reported by all stations. It should normally be expected that if conditions are not favorable for numerous showers, they would not be favorable for large amounts of rain in these showers. Also, the probability of the heaviest rain from any one shower falling on one station is smaller if fewer showers occur in the area.

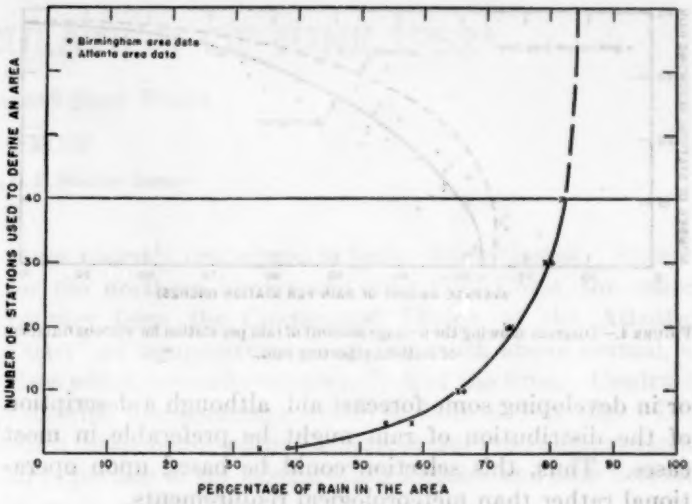

FIGURE 2.—Diagram showing the percentage of days when at least one station within a group of 1, 5, 10, 20, 30, or 40 stations reported rain. Data from both the Birmingham and Atlanta areas are for the 5 summer seasons, 1946–1950. Dashed portion of curve is extrapolated and thus uncertain.

The relation between the average amount of rain per station and the number of stations reporting this rain is shown in figure 4. The curve shown here was fitted by eye and while there is some variation in the average amount for any given number of stations reporting rain, there is a rather good relation between them. For example, when only 10 stations over this area reported rain on the same day, the average amount was about .30 inch but when 30 stations reported rain, average amounts were nearly twice as great. However, when fewer than 15 stations reported rain on one day, the variation in the average amount of rain per station and the number of stations reporting this rain is small. Whether this effect is real or due to a few errors in the data is not certain. In checking over the maximum amount reported by any one station it was found that if only one or two stations of the 40 reported rain, the amount never exceeded two inches while nearly eight inches were reported by one station on a date when 34 stations reported rain. In general, then, it appears that the relation between the average amount per station and the areal coverage for this area and season would justify the selection of either term for use in forecasting

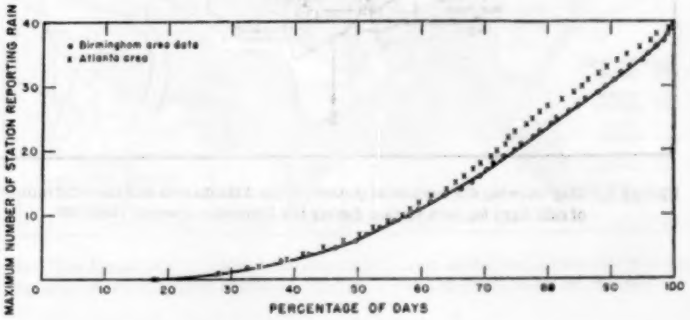

FIGURE 3.—Diagram showing the percentage of days when the indicated maximum number of stations reported rain. Data from both Birmingham and Atlanta areas are for the 5 summer seasons, 1946–1950.

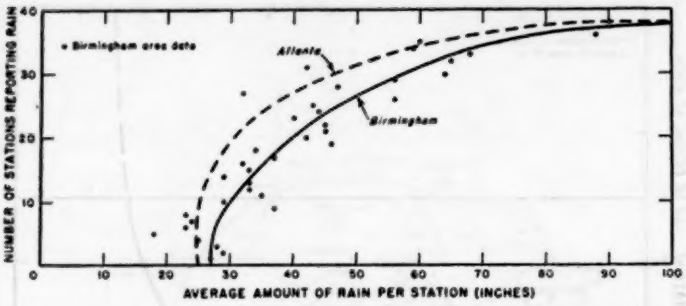

FIGURE 4.—Diagram showing the average amount of rain per station for various numbers of stations reporting rain.

or in developing some forecast aid, although a description of the distribution of rain might be preferable in most cases. Thus, this selection could be based upon operational rather than meteorological requirements.

RESULTS FOR THE ATLANTA AREA

As an additional check on the validity of the interpretations which have been made of these data in the Birmingham area, similar data were analyzed for the Atlanta, Ga., area. Again, a circle with a radius of about 50 miles around the Atlanta Airport was used to determine the area, and precipitation data were compiled for 40 stations for the same reasons as previously used. These data are plotted as circles on figures 2 and 3 and as a dashed curve,

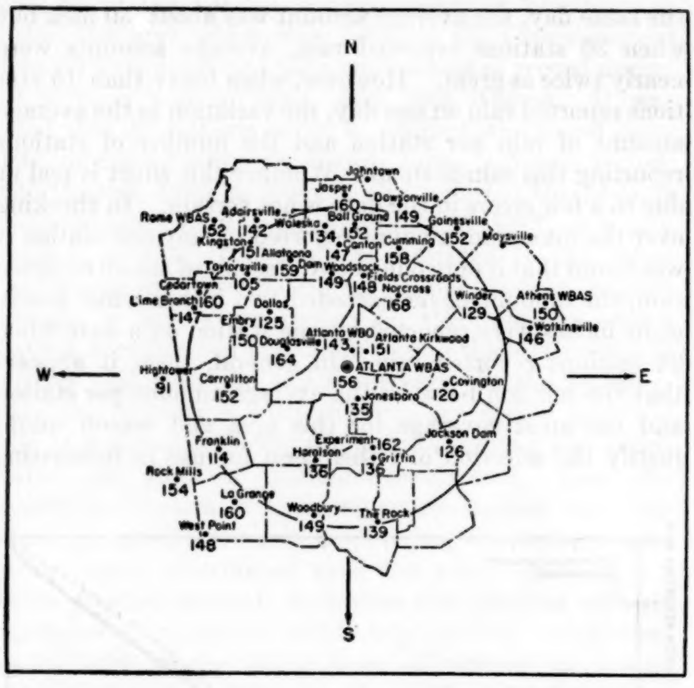

FIGURE 5.—Map showing the location of stations in the Atlanta area and the total number of rain days for each station during the 5 summer seasons, 1946–1950.

which was fitted by eye, on figure 4. The agreement in frequency of rain occurrence between these two areas as shown in figures 2 and 3 is remarkably good and tends to confirm the conclusions which were drawn from the Birmingham data. The total number of rain days in the Atlanta area over this 5-year period for each station is shown in figure 5. While slightly fewer showers occurred in this area, as well as a little less total rainfall, the differences in the total number of rain days between adjacent stations or different sections of this area are somewhat smaller than those in the Birmingham area. Thus, the conclusion that the occurrence of rain is distributed in a random manner seems to be further strengthened.

CONCLUSIONS

Figures 2 and 3 clearly illustrate that data from a single point of observation are all too frequently misleading in these areas during the summer season. The forecaster is dealing with maps which show data from many stations but in general they are located rather far apart as compared with the spacing used in this study. No more than 3 of these 40 stations in either the Birmingham or Atlanta area are available for the synoptic surface maps, and it may be noted that a value of 3 stations is located at a point on the curve in figure 3 where the percentage of rain days is changing rapidly. Thus, there must be many cases of, say, "scattered showers" or perhaps even "numerous showers" of which the forecaster is unaware simply because data on their occurrence were not available to him until weeks later. Since the maps used in his daily work do not permit an accurate appraisal of shower distribution in many cases, it is virtually impossible for the forecaster to build up a picture in his mind of exactly those conditions which subsequently result in various areal coverages of showers. This deficiency is equally important in the development of objective methods of forecasting, and this points up the importance of using all available precipitation reports when studying the forecasting of summer shower occurrence.

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2. Ray K. Linsley and Max A. Kohler, "Variations in Storm Rainfall over Small Areas," *Transactions*, American Geophysical Union, vol. 32, No. 2, April 1951, pp. 245-250.
3. U. S. Weather Bureau, *Climatological Data for the United States by Sections*, Part I, Eastern United States, 1946 through 1950.

THE WEATHER AND CIRCULATION OF JUNE 1952 [1]

A Month With A Record Heat Wave

WILLIAM H. KLEIN

Extended Forecast Section, U. S. Weather Bureau

THE HEAT WAVE

One of the most extensive and prolonged heat waves of recent years dominated the weather of June 1952 in the eastern two-thirds of the United States. This was the hottest June on record in over a dozen cities located in a broad belt stretching from the foothills of the Colorado Rockies to the Carolina coast. The greatest monthly mean temperature anomaly (+10° F) was reported in Kansas City, Mo. (Chart I–B). The monthly mean temperature of 85° F. recorded in Nashville, Tenn. (Chart I–A) not only exceeded the previous June record by 3° but also was higher (by almost 2°) than the temperature for any other month in history. In that city the daily maximum was over 100° F. on each of the last eight days of June and over 90° F. on the last 28 days. The heat wave was particularly severe in the last week of the month, when temperatures of 100° F. or higher were general as far north as Boston and Detroit, and many all-time record high temperatures were equalled or exceeded. On June 27 the nation's capital had its hottest night in 80 years of record when the temperature dropped no lower than 82° F. from a maximum of 101° F. the preceding afternoon.

The magnitude and extent of this month's hot weather is well illustrated in figure 1-A, where the surface temperature anomaly is analyzed in terms of five classes. Except for the northern border and west Gulf Coast, the entire country from the Continental Divide to the Atlantic Coast had temperatures averaging much above normal, a class which normally occurs only 1/8 of the time. Contrast this with the situation existing in June of 1951 (fig. 1-B), when much-below-normal temperatures were observed in a large portion of the central United States and near normal in much of the East.

The striking temperature difference between the past two Junes extended to all levels of the observed atmosphere. This is illustrated by mean soundings for the two months at Omaha, Nebr., figure 2. Temperatures during June 1952 averaged warmer than those during June 1951 at all levels of the troposphere, but the reverse temperature distribution existed in the stratosphere. The normal June sounding for Omaha [1] has not been reproduced because it lies approximately half way between the two ascent curves given in figure 2. It is noteworthy that the temperature difference between June 1952 and June 1951 was greatest at the surface, fairly constant in the upper troposphere (600 to 200 mb.), at a minimum near the tropopause, (200 to 150 mb.), and then large, but of opposite sign, in the stratosphere (from 150 mb. upward).

The contrast between the temperatures of the past two Junes was reflected in the monthly mean circulations at the 700-mb. level. During June 1951 (fig. 3) 700-mb.

[1] See Charts I–XV following page 109 for analyzed climatological data for the month.

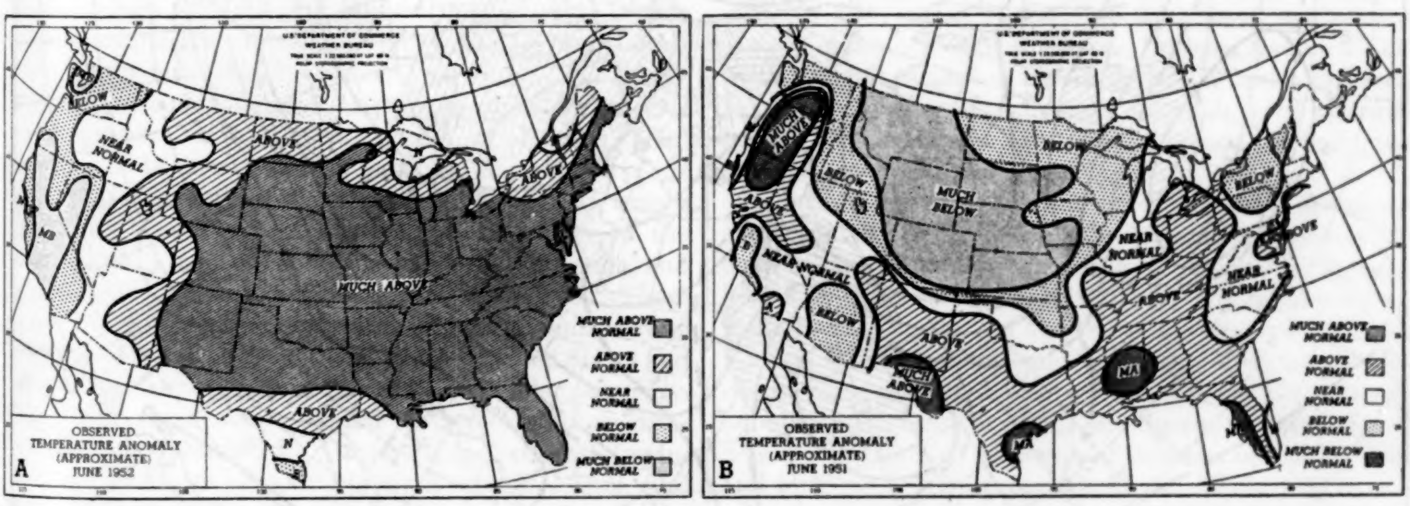

FIGURE 1.—Monthly mean surface temperature anomalies for June 1952 (A) and June 1951 (B). The classes above, below, and near normal occur on the average one-fourth of the time, while much above and much below each normally occur one-eighth of the time. Areas of above and much above are hatched; below and much below are stippled.

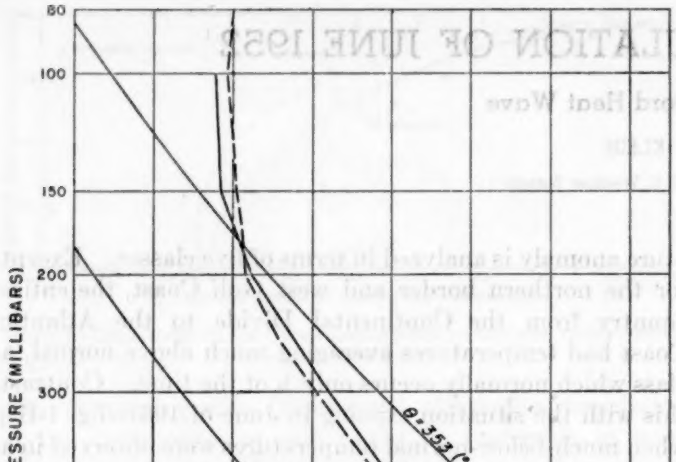

FIGURE 2.—Monthly mean soundings at Omaha, Nebr. for June 1952 (solid line) and June 1951 (dashed line). Two potential temperature lines (θ=283 and θ=353) are given for reference.

heights were below normal in much of the United States, and the central part of the country was dominated by cyclonically-curved flow around a deep mean trough stretching from North Dakota to southern California. Repeated surges of cold polar continental air were carried into this trough by abnormally strong northwesterly flow emanating in a pronounced ridge in the eastern Pacific and Alaska. Further details concerning the weather and circulation of June 1951 can be found in an earlier article of this series [2].

Examine now the mean 700-mb. circulation for June 1952, figure 4. Almost the entire United States east of the Rocky Mountains was under the influence of anticyclonic curvature, anticyclonic shear, and above-normal heights north of a well-developed High centered on the east Gulf Coast. These conditions were favorable for abundance of clear skies (Chart VI), sunshine (Chart VII), and heating by solar radiation (Chart VIII). Furthermore, stronger-than-normal flow between the High on the Gulf Coast and a deep mean trough located along the west coast of the United States transported an unusually large amount of air from the hot desert regions of the Southwest into the central United States. From there the warm air spread eastward to the Atlantic Coast in a stream of abnormally strong westerlies along the northern border of the country, downstream from a pronounced zone of confluence. These westerlies were effective in preventing any appreciable penetration into the United States of cool polar air from Canada and the Arctic. Although cool polar Pacific air masses did enter the country at frequent intervals, they were confined mostly to the Far West, and were rapidly warmed after crossing the mountains.

The question naturally arises: Was the circulation pattern of June 1952 typical of heat wave situations in summer in the central United States? In order to shed some light on this problem a composite map was prepared by averaging the 700-mb. height anomaly observed during the 10 hottest 5-day mean periods (non-consecutive) at Kansas City during the summer months (June, July, and

FIGURE 3.—Mean 700-mb. chart for the 30-day period May 28–June 27, 1951. Contours at 200-ft. intervals are shown by solid lines, intermediate contours by lines with long dashes, and 700-mb. height departures from normal at 100-ft. intervals by lines with short dashes with the zero isopleth heavier. Anomaly centers and contours are labeled in tens of feet. Minimum latitude trough locations are shown by heavy solid lines. Areas with 700-mb. height anomalies in excess of +100 ft. are hatched; areas with anomalies less than −100 ft. are stippled.

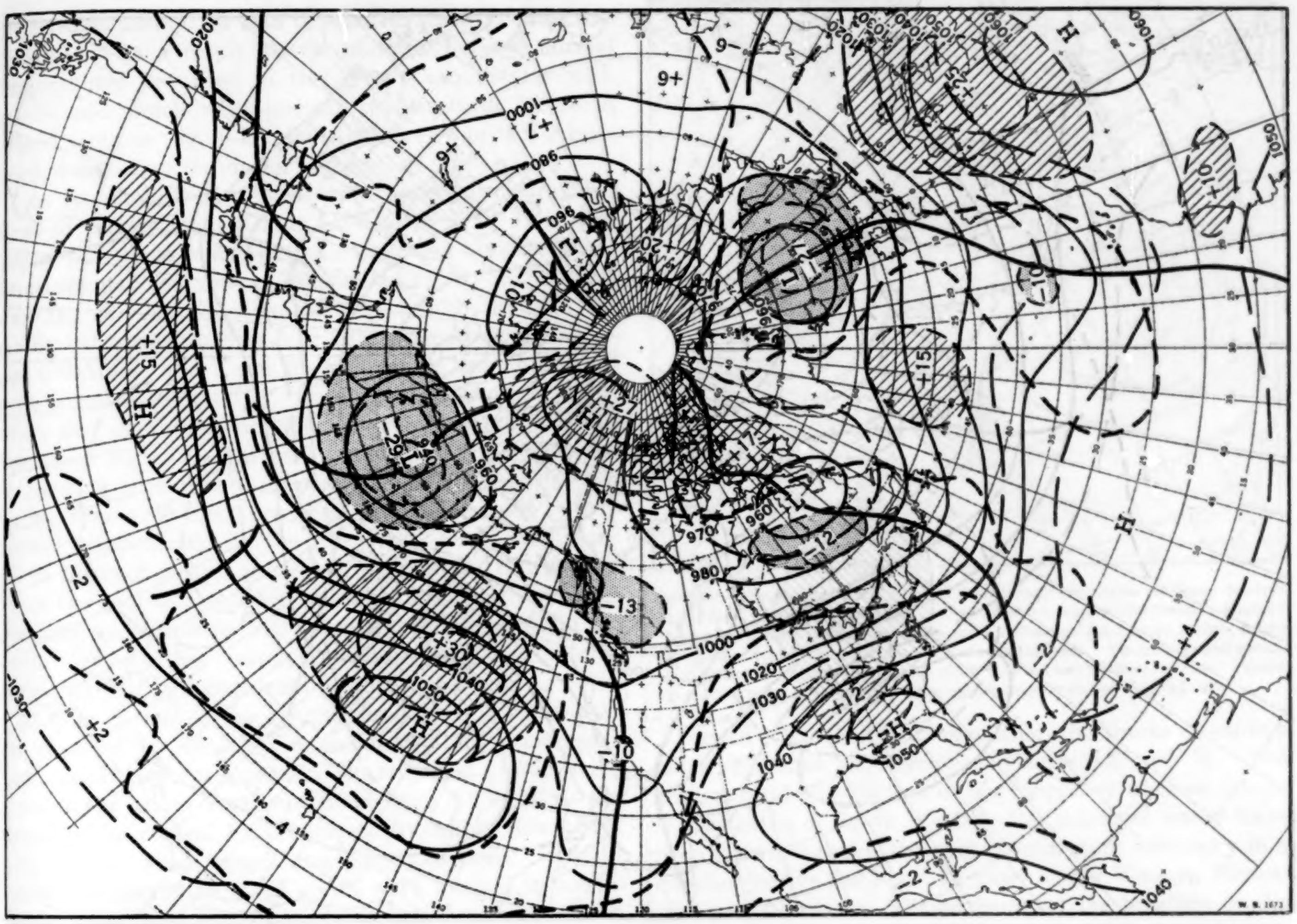

FIGURE 4.—Mean 700-mb. chart for the 30-day period June 1–29, 1952. Contours at 200-ft. intervals are shown by solid lines, intermediate contours by lines with long dashes, and 700-mb. height departures from normal at 100-ft. intervals by lines with short dashes with the zero isopleth heavier. Anomaly centers and contours are labeled in tens of feet. Minimum latitude trough locations are shown by heavy solid lines. Areas with 700-mb. height anomalies in excess of +100 ft. are hatched; areas with anomalies less than −100 ft. are stippled.

August) from 1947 through 1951.[2] These anomalies were then converted to actual 700-mb. heights by adding them to the normal 700-mb. height for June. The resulting composite map, figure 5, can now be compared directly with the chart for June 1952, figure 4. Common characteristics of both maps are a stronger-than-normal ridge in the Mississippi Valley, a deeper-than-normal trough along the West Coast, a relatively weak trough off the East Coast, a zone of confluence in southern Canada, and below-normal 700-mb. heights in most of Canada. These conditions are ideal for generating and maintaining strong currents of warm air from the southwest United States and preventing any appreciable influx of cooler air from Canada or the oceans. Similar features appear on composite maps published by Martin [3] for extremely warm summer cases in Boston, Mass., Evansville, Ind., and Denver, Colo. *Thus it appears that the circulation pattern of June 1952 was typical of that observed during summer heat waves in most of the central and eastern United States.* The resemblance between figures 4 and 5 also extends to most of the Pacific and Atlantic and even to central Europe. It is believed that this is indicative of large-scale interaction between component parts of the general circulation and is not merely fortuitous.

Figure 5 is based on only ten cases. In order to demonstrate that the interrelation between temperature and circulation described above is generally applicable, figure 6 has been prepared by using data for all summer 5-day mean periods during the 4 years from 1946 through 1949. For these 105 periods simple linear correlation coefficients were computed between the surface temperature anomaly at Kansas City (°F.) and the concurrent 700-mb. height anomaly (ft.) at standard intersections of latitude and longitude. The geographical distribution of the resulting correlation coefficients is given in figure 6. A similar correlation field, for winter temperatures at Eureka, Calif., has been published in an earlier article of this series [4]. Figure 6 shows that above-normal temperatures in Kansas City in summer are generally accompanied by above-normal 700-mb. heights in the eastern two-thirds of the United States and the eastern Pacific, where the cor-

[2] It would be preferable to use data for the month of June only and for 30-day rather than 5-day mean periods. However, the existing file of 700-mb. maps is inadequate for selecting enough cases with good hemispheric analyses on this basis. Furthermore, the interrelation between weather and circulation is generally similar for 5-day and 30-day mean periods.

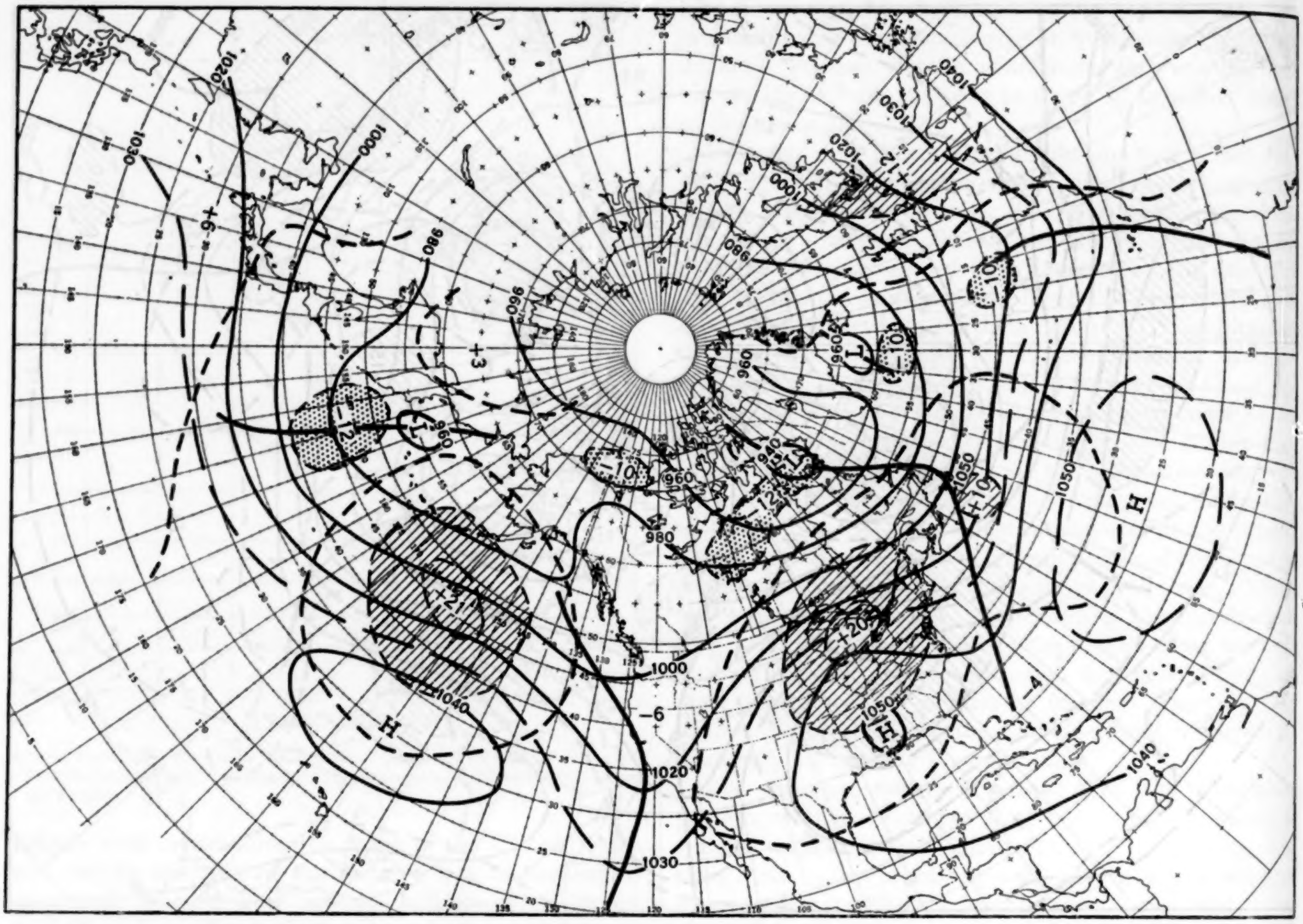

FIGURE 5.—Mean 700-mb. chart for the ten 5-day mean periods with largest positive surface temperature anomaly observed at Kansas City during the past 5 summers (1947-1951.) Contours at 200-ft. intervals are shown by solid lines, intermediate contours by lines with long dashes, and 700-mb. height departures from normal at 100-ft. intervals by lines with short dashes with the zero isopleth heavier. Anomaly centers and contours are labeled in tens of feet. Minimum latitude trough locations are shown by heavy solid lines. Areas with 700-mb. height anomalies in excess of +100 ft. are hatched; areas with anomalies less than −100 ft. are stippled.

relations are positive, but below-normal heights in Canada (except the southeast part) and the West Coast region, where the correlations are negative; and conversely for cool weather. The center of maximum correlation, in the Ohio Valley, and the secondary center, in the eastern Pacific, are located close to centers of positive 700-mb. height anomaly in figures 4 and 5, while the center of negative correlation, in central Canada, is occupied by below-normal 700-mb. heights in figures 4 and 5. *In fact, here is a striking parallelism between the lines of equal correlation in figure 6 and the lines of equal 700-mb. height anomaly in figures 4 and 5.* Thus the fundamental interrelations between temperature and circulation illustrated for extremely warm cases can be extended essentially intact to a much larger number of cases.

OTHER ASPECTS OF THE WEATHER AND CIRCULATION

While residents of the eastern and central United States were sweltering, the Far West experienced an unusually cool month. Monthly mean temperatures of as much as 6° F. below normal were reported in the interior valleys of California (Chart I–B). The minimum temperature of 44° F. in Sacramento on June 12 was the lowest ever recorded so late in the season and within 1° of the lowest temperature on record for June. On the same date several inches of snow fell in northeastern Oregon, and below-freezing minima were reported at several interior stations as far south as Reno, Nev., where the existing low temperature record for June was broken.[3] Cool weather in this region was associated with excessive cloudiness (Chart VI) and below-normal heights in the vicinity of a deep mean trough at 700 mb. (fig. 4). Recurrent outbreaks of cool maritime polar air overspread the Far West, generated by stronger-than-normal northwesterly flow in the eastern Pacific, between the West Coast trough and an intense ridge located along the 150° W. meridian. The fact that this ridge was about 15° farther west than its counterpart during June 1951 is believed to be a major factor responsible for the difference in weather and circulation of the two months. Last year, the Pacific ridge was sufficiently far east to interrupt the flow of polar maritime air into the Far West, but the flow

[3] For further details see adjoining article by Hughes and Ross.

of polar continental air into the central United States was enhanced. As a result above- and much-above-normal temperatures prevailed in the West Coast States with below- and much-below-normal temperatures in north central sections (fig. 1–B); just the reverse of this June's temperature distribution for these areas (fig. 1–A).

The anomalies of temperature generally paralleled those of precipitation (Chart III and fig. 7). It is well known that there is a negative correlation between these two elements in summer. Thus in the region of abnormal warmth, east of the Continental Divide, rainfall was mostly subnormal during June 1952. In parts of Arkansas, Oklahoma, and Texas no measurable amounts at all were recorded (Chart II). Conversely, in the Far West, where cool conditions prevailed, heavy precipitation was the rule. Statewide amounts averaged more than twice as great as normal in California and Oregon. Likewise, during June 1951 light precipitation accompanied above-normal temperatures in the Far West, but heavy rains fell in the cool central and eastern sectors. During both years the cool wet weather was associated with cyclonic vorticity and below-normal heights at 700 mb., while the warm dry weather was accompanied by anticyclonic curvature with above-normal heights at 700 mb.

Further details of the general circulation in June 1952 are revealed by the field of mean 700-mb. geostrophic wind speed shown in figure 8. The strongest average wind speed in the entire Northern Hemisphere (16 m. p. s.) was found in the central Pacific, in southwesterly flow about half way between trough and ridge positions. Weaker centers of maximum wind speed were located in southwesterly flow just east of mean troughs in southwestern United States, western Atlantic and western Europe. Another strong center of maximum wind speed was located in west-northwesterly flow just south of James Bay, downstream from a confluence zone near Lake Winnipeg. The axes of maximum speed (jets) were clearly marked in the oceans but indistinct over western North America, where three weak branches were in evidence.

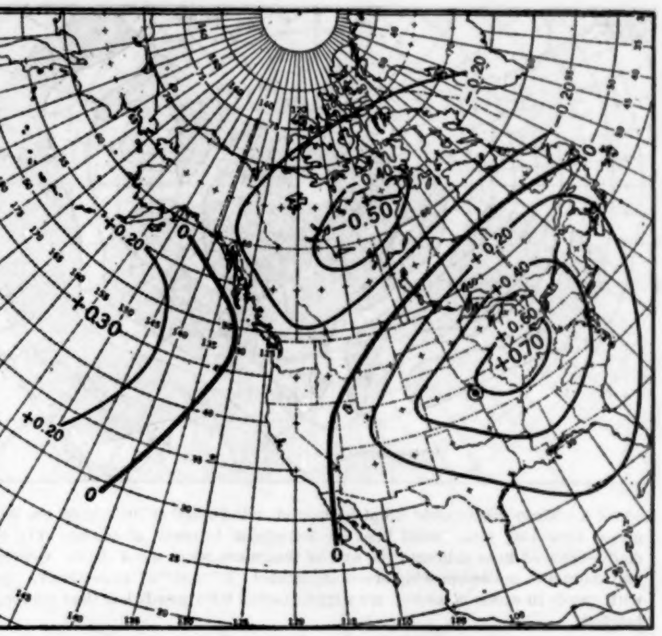

FIGURE 6.—Geographical distribution of simple linear correlation coefficient between 5-day mean surface temperature anomaly in summer at Kansas City (location shown by heavy black circle inside open circle) and simultaneous 5-day mean 700-mb. height anomaly at standard intersections of latitude and longitude. The lines of equal correlation coefficient are drawn at intervals of 0.20 with the zero isopleth heavier. Centers of maximum and minimum correlation are labeled with highest observed value.

Figure 8 is useful in interpreting the tracks of centers of anticyclones and cyclones, Charts IX and X. The geographical distribution of the frequency of these tracks is illustrated in figure 9, where the principal tracks have been drawn through the axes of maximum frequency in a quasi-objective fashion. In most of the Western Hemisphere some relation existed between the location of the 700-mb. jet streams and the principal tracks of both anticyclones and cyclones, as previously noted [5]. The former track was generally found in the region of anticyclonic wind shear to the right of the jet (looking downstream), while the latter was located in cyclonic shear to the north. However, the distance between the tracks and the jets varied considerably in different parts of the world. It should also be noted that the regions of greatest cyclone

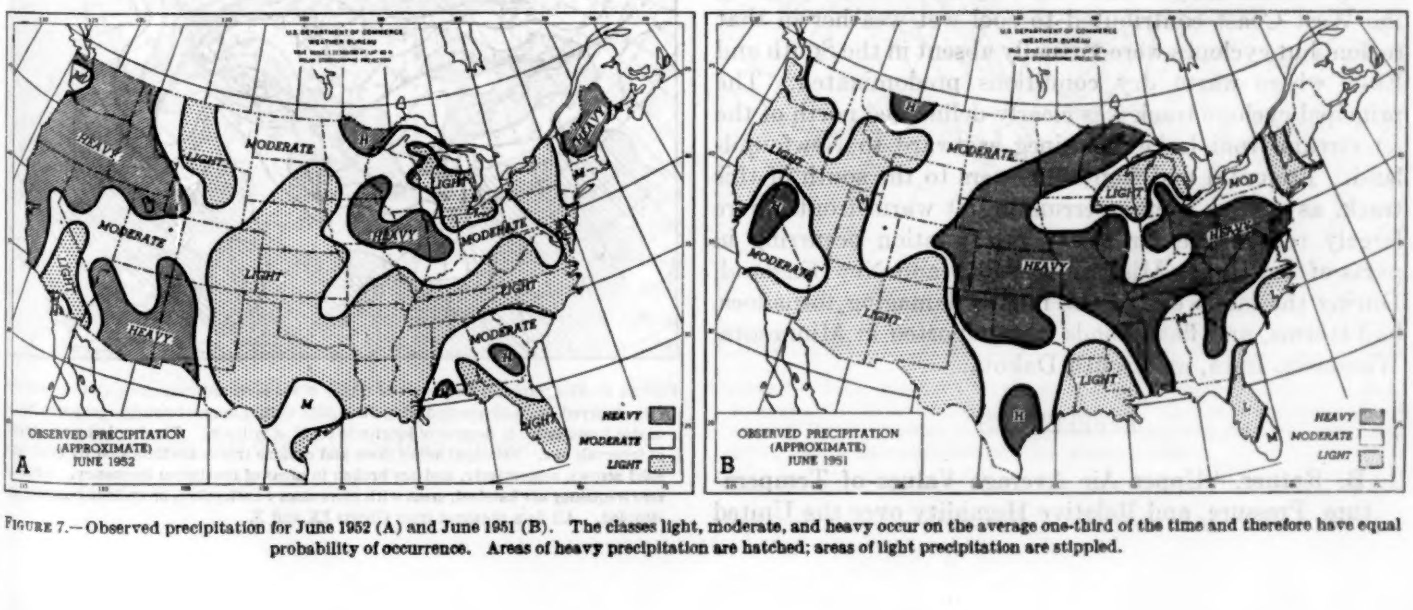

FIGURE 7.—Observed precipitation for June 1952 (A) and June 1951 (B). The classes light, moderate, and heavy occur on the average one-third of the time and therefore have equal probability of occurrence. Areas of heavy precipitation are hatched; areas of light precipitation are stippled.

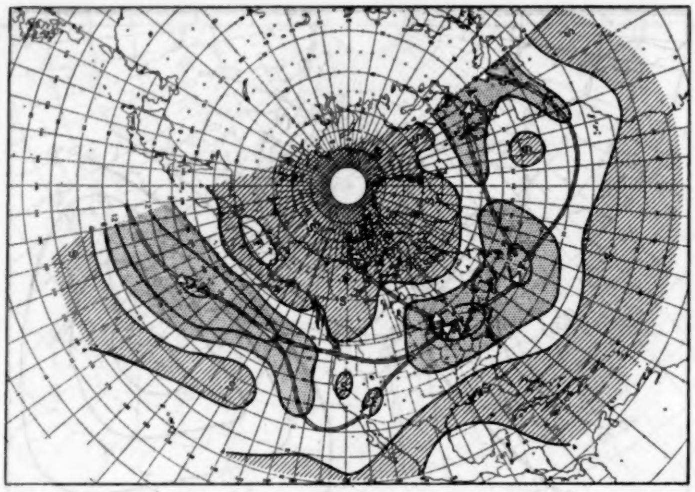

FIGURE 8.—Mean geostopohic (total horizontal) wind speed at 700 mb. for the 30-day period June 1-30, 1952. Solid lines are isotachs at intervals of 4m/sec. The open double-arrowed lines delineate the axes of maximum wind speed (jets). Centers of maximum and minimum wind speed are labeled "F" and "S" respectively. Areas with speeds in excess of 8m/sec. are stippled; areas with speeds less than 4m/sec. are hatched.

frequency, near James Bay and Newfoundland, were located just north of centers of maximum wind speed, while anticyclones were frequent just south of these centers. This illustrates the well known tendency for the westerlies aloft to be strongest just south of deep Lows and just north of Highs at sea level.

The prevailing tracks of anticyclones and cyclones were related to the anomalies of temperature and precipitation. Offshoots of the quasi-permanent eastern Pacific High brought cool air into the Far West at frequent intervals throughout the month. These migratory anticyclones either dissipated in the southern Rocky Mountains or moved rapidly eastward along the northern border of the United States, where they were reinforced by Highs of polar continental origin. Very few of these systems penetrated south of 40°N. in the United States. As a consequence they had little cooling effect upon the eastern two-thirds of the Nation, except for the extreme northern border where temperatures averaged near normal for the month. Unusually well-marked cyclonic activity along the West Coast contributed to cool wet weather in that region, but cyclones were virtually absent in the South and East, where warm dry conditions predominated. The principal cyclone track was clearly delineated north of the jet stream from Lake Winnipeg eastward to Newfoundland. Prefontal and frontal showers to the south of this track, as well as some overrunning at warm fronts, were largely responsible for heavy precipitation occurring in parts of the Upper Mississippi Valley and New England. During the last week of the month damaging tornadoes, hail storms, and flash floods were reported in Minnesota, Wisconsin, Iowa, and South Dakota.

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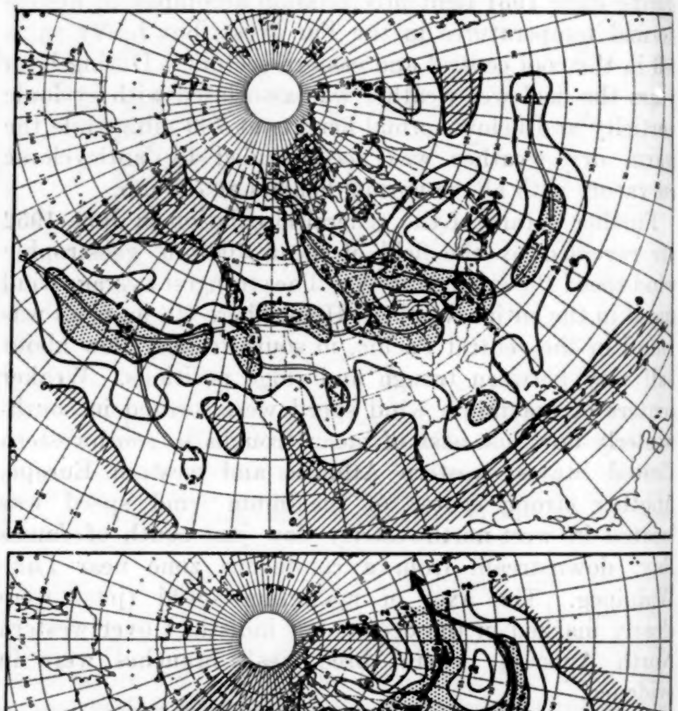

FIGURE 9.—Geographical frequency of tracks of sea level anticyclones (A) and cyclones (B) observed on daily maps during June 1952 within approximately equal-area boxes of size 5 mid-latitude degrees of longitude by 5° of latitude. The isopleths are drawn at intervals of 2. Principal anticyclone and cyclone tracks are indicated by open and solid arrows, respectively, and are broken in areas of maximum frequency. Areas of zero frequency are hatched; areas with more than 4 anticyclone or cyclone passages are stippled. All data obtained from Charts IX and X.

LOW MINIMUM TEMPERATURES OF JUNE 12-13, IN THE FAR WEST

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INTRODUCTION

During the month of June 1952, upper level pressures were below normal on the West Coast with resultant below-normal mean temperatures in the Far West [1]. This article deals with the most intense cold outbreak of this period, the record to near record breaking minimum temperatures in California, Nevada, Oregon, Washington, and Idaho on the mornings of the 12th and 13th of June. The cold surge that caused these low temperatures is traced from Alaska to the West Coast. The movement of the cold air inland immediately followed by warm advection can be accounted for by the shifting in orientation of the upper level trough. The shifting of this trough is shown to be directly related to additional influxes of cold air from Canada.

ANTECEDENT CONDITIONS

A surface wave, which developed off the east coast of Japan on June 1, had moved by June 6 to a position just south of Dutch Harbor, Alaska, and there reached a maximum depth of 973 mb. This storm was unusually intense for this time of the year [2].

The upper level charts for June 6 showed that exceptionally cold air flowing southward from Bering Sea had moved in behind the deep surface storm. The surface storm filled as it moved northward over Bering Sea and its surface fronts dissipated. However, the cold air aloft moved to the east giving temperatures at 700 mb. of −10° C. at Bethel, Alaska, −16° C. at Adak, Alaska on June 7, and −13° C. at Anchorage, Alaska on June 8. These temperatures are near the record for June for the short period that upper air soundings have been taken in that area [3].

The cold Low maintained a closed circulation at 500 mb. and began to move to the southeast, although surface pressures over the northeast Pacific remained relatively high. The approach of the cold air, which at 700 mb. was centered south of Kodiak, Alaska on June 8, encouraged the flattening of the sharp north-south surface ridge in the eastern Pacific and the building of a warm ridge over western Alaska. By the morning of the 10th the 500-mb. low pressure system, which had deepened somewhat and now appeared as a closed circulation at the 700-mb. level, was centered off the British Columbia coast. An old cutoff Low which had been stationary for more than a week off the California coast now moved inland with subsequent frontogenesis over the Plateau Region.

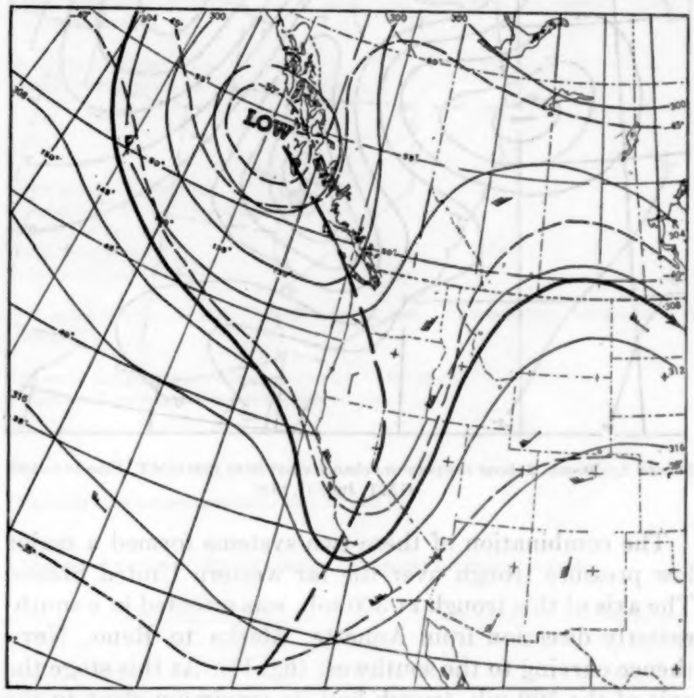

FIGURE 1. 300-mb. chart for 0300 GMT, June 10, 1952. Contours (solid lines) at 400-ft. intervals are labeled in hundreds of geopotential feet. Isotherms (dashed lines) are in intervals of 5° C. Heavy dashed line represents low-pressure trough. Heavy solid line represents jet stream. Barbs on wind shafts are for wind speeds in knots; full barb=10 knots, half barb=5 knots, and pennant=50 knots.

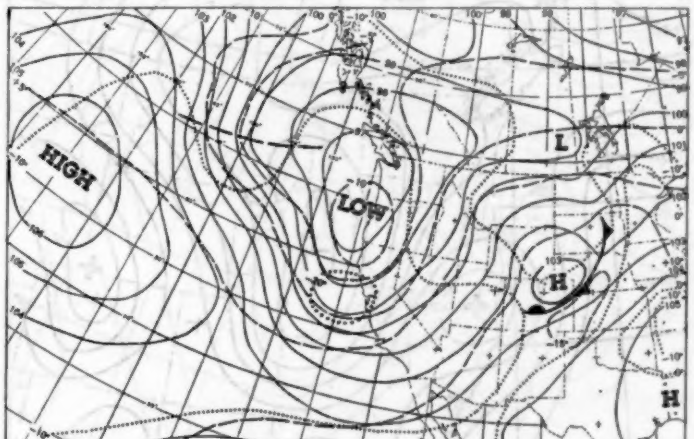

FIGURE 2.—700-mb. chart for 1500 GMT, June 11, 1952. Contours (solid lines) at 100-ft. intervals are labeled in hundreds of geopotential feet. Isotherms (dashed lines) are at intervals of 5° C. Isograms of dew point temperature (dotted lines) are at intervals of 10° C. Heavy dashed line represents low-pressure trough.

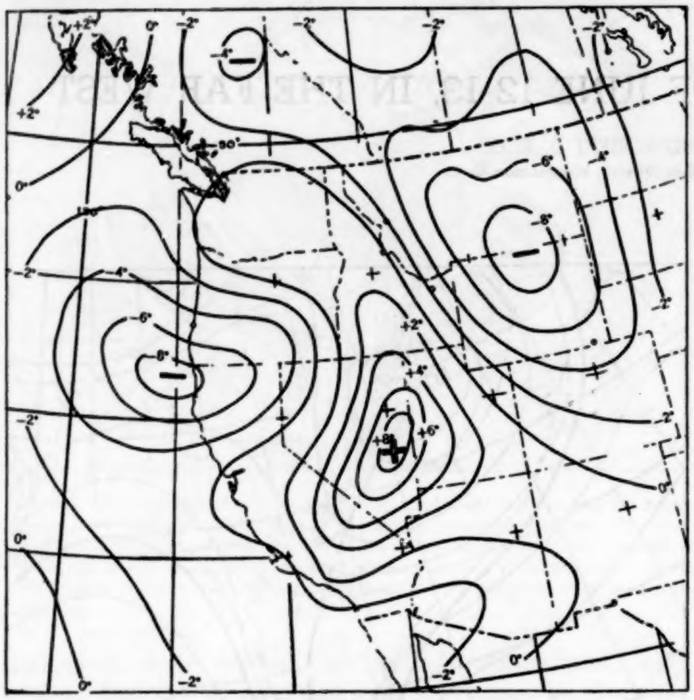

FIGURE 3.—700-mb. 24-hour temperature change chart from 1500 GMT, June 10 to 1500 GMT, June 11, 1952.

The combination of these two systems formed a major low pressure trough over the far western United States. The axis of this trough at 300 mb. was oriented in a southeasterly direction from Annette, Alaska to Reno, Nev., thence curving to the southwest (fig. 1). At this stage the axis of the 300-mb. trough had its maximum slant to the southeast.

MOVEMENT OF COLD AIR INLAND

The 700-mb. chart for June 11 at 0300 GMT (not reproduced) shows that the cold air had moved southward to just off the Washington-Oregon coast producing near record 700-mb. temperatures at Tatoosh and Seattle, Wash. [3]. Twelve hours later the 700-mb. temperature at Medford, Oreg. fell to −12° C. (fig. 2), about 4° colder than the previous record at this station during June over a 6-year period [3]. The rapid temperature changes that were taking place aloft over the West are indicated by the 24-hour 700-mb. temperature change charts, June 10 to June 13 (figs. 3, 4, and 5).

After the Low aloft had reached the Oregon coast a tongue of cold air moved inland with cyclogenesis taking place at the surface over Idaho and Nevada (fig. 6). By 0030 GMT, June 12, cold frontogenesis was indicated from western Montana southward to southern California with snow showers reported over the mountain areas of Oregon and northern California. The intensity of the cold air at 700-mb. is indicated by the temperatures of −7.5° C. at Oakland, Calif. at 0300 GMT, June 12, and −9° C. at Boise, Idaho, at 1500 GMT, June 12, both near record for June.

LOW SURFACE TEMPERATURES

On the morning of the 12th minimum surface temperatures were unusually low over Washington, Oregon, Nevada, and California (fig. 8) with many stations reporting new minimum temperature records for June (see table 1). Frost occurred in local areas of northern California,

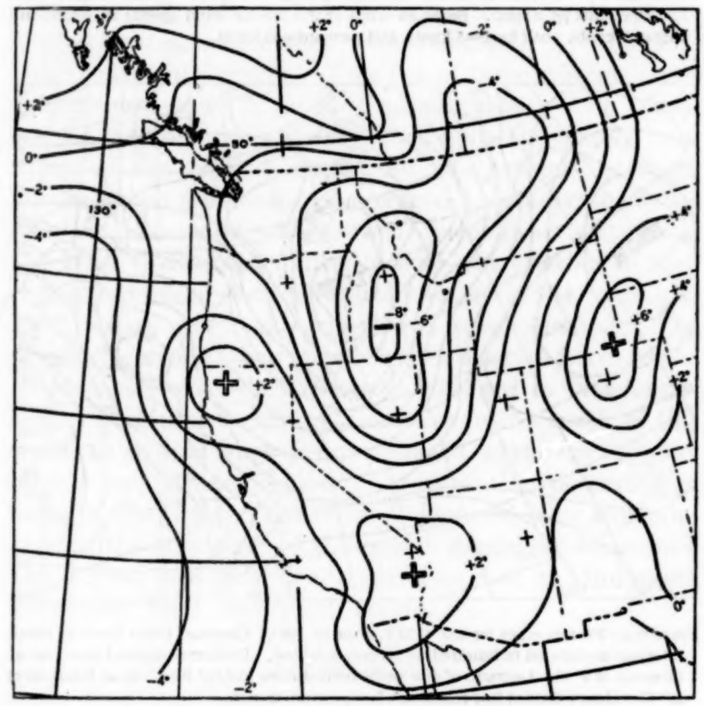

FIGURE 4.—700-mb. 24-hour temperature change chart from 1500 GMT, June 11 to 1500 GMT, June 12, 1952.

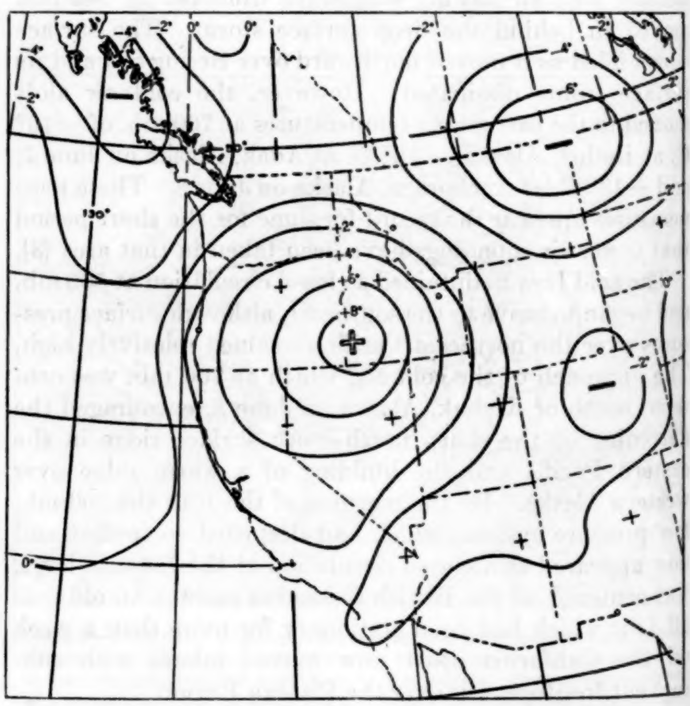

FIGURE 5.—700-mb. 24-hour temperature change chart from 1500 GMT, June 12 to 1500 GMT, June 13, 1952.

TABLE 1.—*Some June minimum temperature comparisons*

	Min. temp. June 12 or 13, 1952	Previous June record min. [4]	Remarks
California	°F.	°F.	
Blue Canyon	28	----	1.4 inches snow, June 11.
Eureka	43	40	
Fresno	47	42	
Mount Shasta	25	----	*"A killing frost on the morning of the 12th . . . on the valley floor where temperatures were quite likely as much as 4° or 5° colder than observed at this station." Trace of snow on the 11th.
Oakland Airport	46	42	
Red Bluff	42	43	New record for June.
Sacramento	44	43	† Lowest temperature for so late in the month.
Oregon			
Baker	32	27	
Eugene	37	36	
Lakeview	28	----	Trace of snow on the 12th.
Meacham	32	----	Trace of hail on 11th, trace of snow on 12th.
Medford	31	32	New record for June.
Pendleton	40	----	Trace of snow on 12th.
Roseburg	35	36	New record for June.
Salem	41	32	
Saxton Summit	29	----	* 1.5 inches of snow on 11th, trace of snow on 12th. "Lowest June temperature on record."
Washington			
Ellensburg	33	----	* "Lowest temperature ever recorded so late in the season."
Olympia	36	----	* "Lowest June temperature since June 14, 1945."
Spokane	38	34	
Tatoosh	44	43	
Nevada			
Elko	27	----	* "Lowest June temperature since June 14, 1945."
Fallon	30	----	
Lovelock	29	----	
Reno	27	28	* New record for June. Killing freeze on 12th caused widespread damage.
Winnemucca	30	29	

* Quoted from remarks section of June 1952 *Local Climatological Data* for each station.
† From the *Weekly Weather and Crop Bulletin*, June 13, 1952.

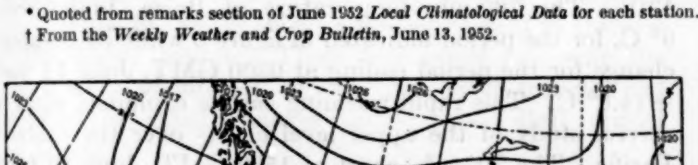

FIGURE 6.—Surface weather map for 1230 GMT, June 11, 1952. Shading indicates areas of active precipitation.

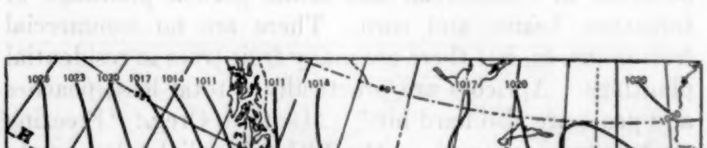

FIGURE 7.—Surface weather map for 1230 GMT, June 12, 1952.

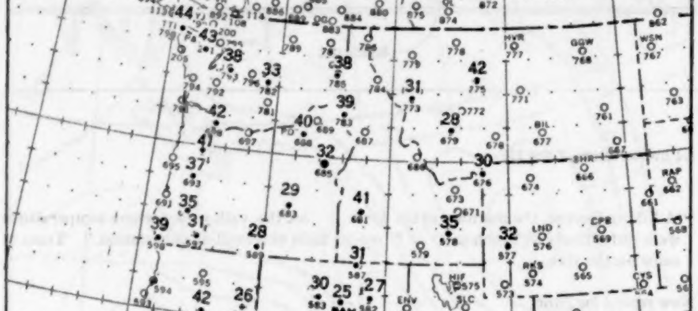

FIGURE 8.—Minimum temperature chart for June 12 and 13, 1952.

Oregon, Washington, and northern Nevada. The following reports of damage are quoted from the June issues of *Local Climatological Data*. Reno, Nev.: "Killing freeze on the 12th caused widespread damage; heavy losses occurred in commercial and home garden plantings of tomatoes, beans, and corn. There are no commercial fruit orchards, but there are many fruit trees in residential plantings. Apricots are practically a total loss; peaches and pears are also hard hit." Medford, Oreg.: "Freezing temperature occurred on the 12th with slight damage to fruit and crops considering the valley as a whole, but some gardens and orchards sustained heavy losses." Spokane, Wash.: "Scattered areas of light frost in the vicinity the morning of the 13th caused considerable damage to tender vegetables and also to the field crops in the lower areas." Mount Shasta, Calif.: "A killing frost on the morning of the 12th completely destroyed most gardens on the valley floor, where temperatures were quite likely as much as 4° or 5° colder than observed at this station."

Most of the coldest temperatures occurred on the morning of the 12th except in Idaho and eastern Nevada where the lowest minima came on the 13th. The main reason for these exceptionally cold temperatures was the deep column of unusually cold air. Of course, radiational cooling, aided by light surface winds, helped lower the surface temperatures during the nights but, due to high moisture aloft throughout this period, radiational cooling apparently was not at a maximum. The few low minima that occurred on the 13th in the Coastal States were due to shallow pools of cold air trapped in the valleys. Generally, however, on the 13th temperatures were rising rapidly along the Pacific Coast, particularly aloft.

SHORT DURATION OF COLD SPELL

An examination of figures 4 and 5 shows initial warming at 700 mb. over California and southern Oregon on the 12th followed by warming throughout the West on the 13th. The 700-mb. temperature at Boise, Idaho rose 9° C. for the period indicated in figure 5 while its 36-hour change for the period ending at 0300 GMT, June 14 was +14.5° C. This rapid warming can be explained after a careful study of the upper level charts over the eastern Pacific. The 700-mb. chart of 1500 GMT, June 10 (not reproduced) shows new but weak cold advection from

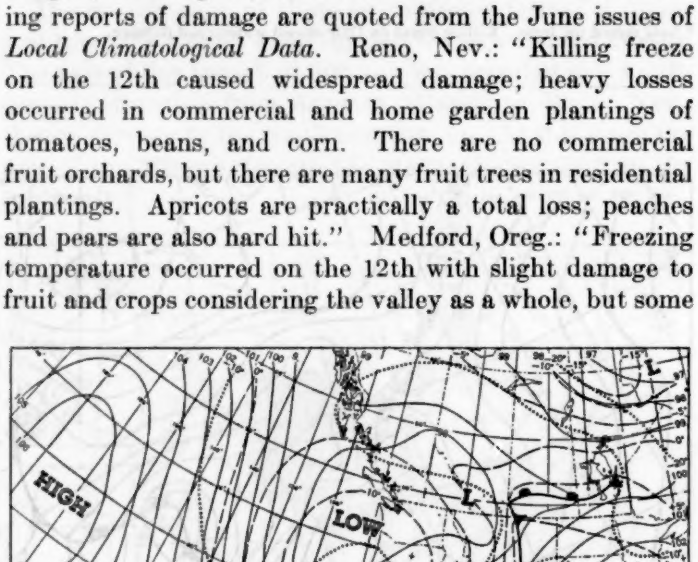

FIGURE 9.—700-mb. chart for 1500 GMT, June 12, 1952. Contours (solid lines) at 100-ft. intervals are labeled in hundreds of geopotential feet. Isotherms (dashed lines) are at intervals of 5° C. Isograms of dew point temperature (dotted lines) are at intervals of 10° C. Heavy dashed line represents low pressure trough.

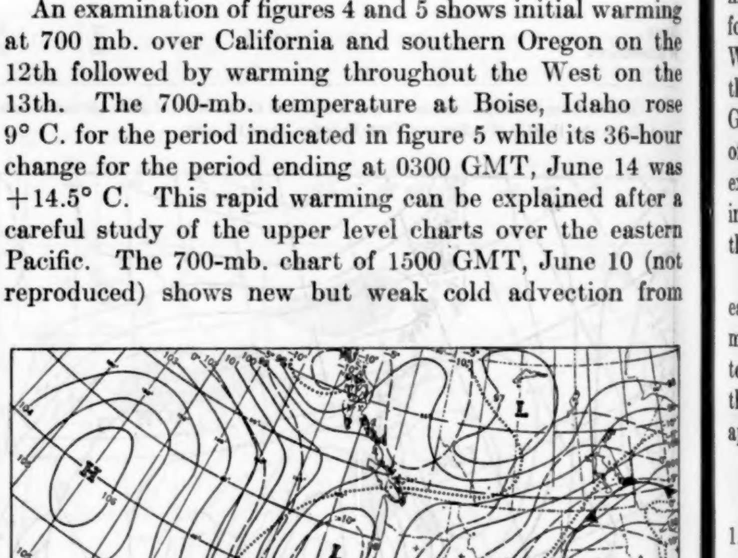

FIGURE 10.—700-mb. chart for 1500 GMT, June 13, 1952. Contours (solid lines) at 100-ft. intervals are labeled in hundreds of geopotential feet. Isotherms (dashed lines) are at intervals of 5° C. Isograms of dew point temperature (dotted lines) are at intervals of 10° C. Heavy dashed line represents low pressure trough.

northwestern Canada toward the south. This air moved into the Gulf of Alaska and by 1500 GMT, June 11 (fig. 2) had resulted in a cold trough moving southward into the major trough. By 1500 GMT, June 12 (fig. 9) this new trough had moved southward off the California coast and deepened so that it now represented the lower portion of the major trough. This deepening off the coast in effect resulted in the retrogression of the southern portion of the major trough.

The 700-mb. winds over California became west-northwesterly at 0300 GMT, June 12 following the passage inland of the trough that accompanied the record-breaking cold air. These winds remained northwesterly for less than 12 hours; the 1500 GMT, June 12 700-mb. chart (fig. 9) shows that the air flow had backed rapidly to the southwest. Temperatures aloft over California, Oregon, and Nevada quickly rose after this wind shift (fig. 4).

Then a third and final surge of cold air entered the picture. The 700-mb. charts indicated further cold air advection south of ship P (50° N., 145° W.) and approaching ship N (33° N., 135° W.) at 1500 GMT, June 13 (figs. 10 and 11). With the approach of this cold air the trough off the California coast moved slowly westward and warming continued over the western States (fig. 5).

By the 13th the lower portion of the major trough had moved to its most westerly position. The 300-mb. chart for 1500 GMT, June 13 (fig. 12) shows a Low near the Washington–Oregon coast with a trough southwestward through ship N. Comparison with the chart for 0300 GMT, June 10 (fig. 1) shows a 90-degree shift in the axis of the major trough. These two maps represent the extremes in orientation of the high level troughs and indicate the rapid changes taking place aloft during this period.

From the 13th on, the trough aloft moved steadily eastward, entered the United States on the 15th, and moved into the Central States. Although on the average temperatures in the Far West remained below normal for the remainder of the month, the minima did not again approach those of the 12th and 13th.

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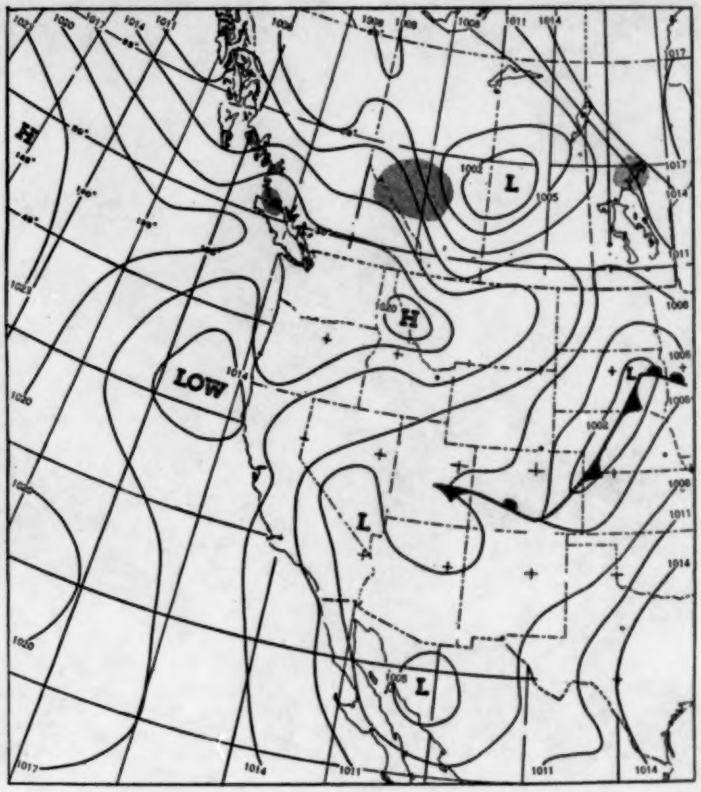


FIGURE 11.—Surface weather map for 1230 GMT, June 13, 1952.

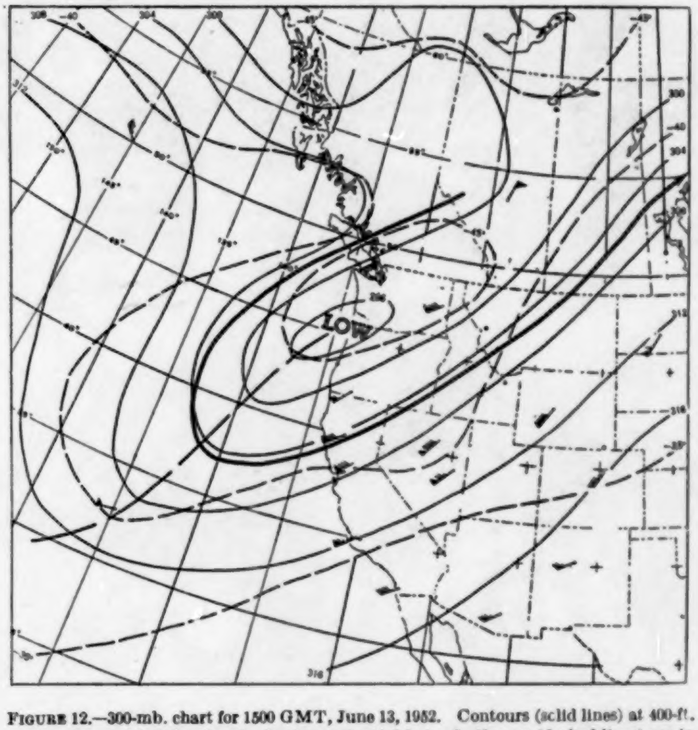
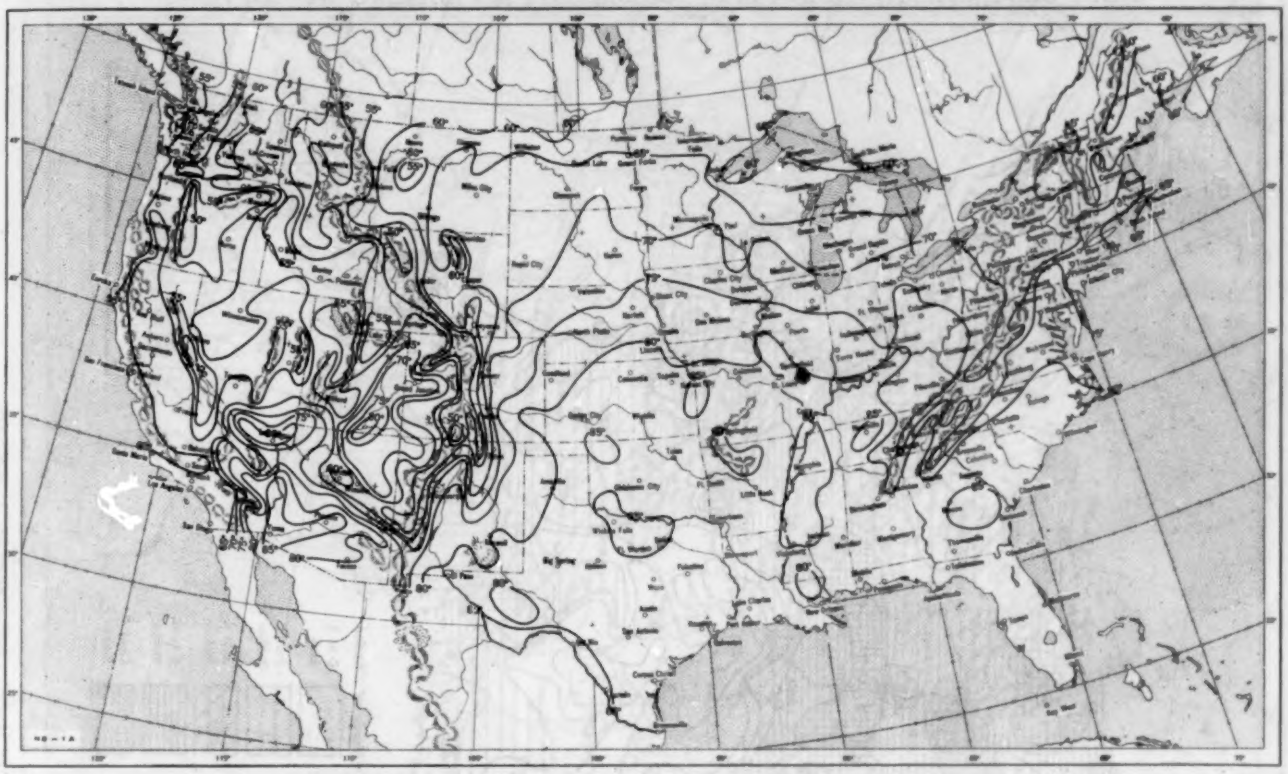


FIGURE 12.—300-mb. chart for 1500 GMT, June 13, 1952. Contours (solid lines) at 400-ft. intervals are labeled in hundreds of geopotential feet. Isotherms (dashed lines) are in intervals of 5° C. Heavy dashed line represents low pressure trough. Heavy solid line represents jet stream. Barbs on wind shafts are for wind speeds in knots; full barb=10 knots, half barb=5 knots, and pennant=50 knots.

U. S. GOVERNMENT PRINTING OFFICE: 1952

Chart I. A. Average Temperature (°F.) at Surface, June 1952.



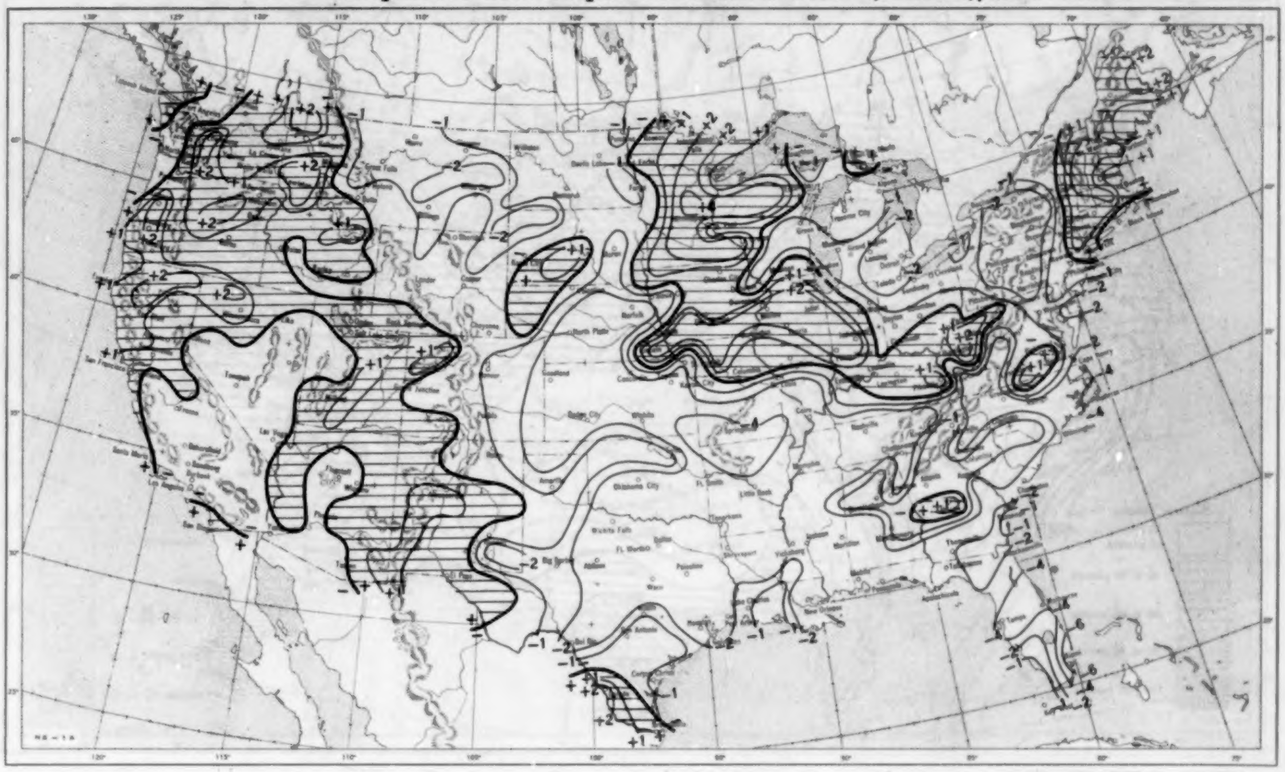
B. Departure of Average Temperature from Normal (°F.), June 1952.

A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

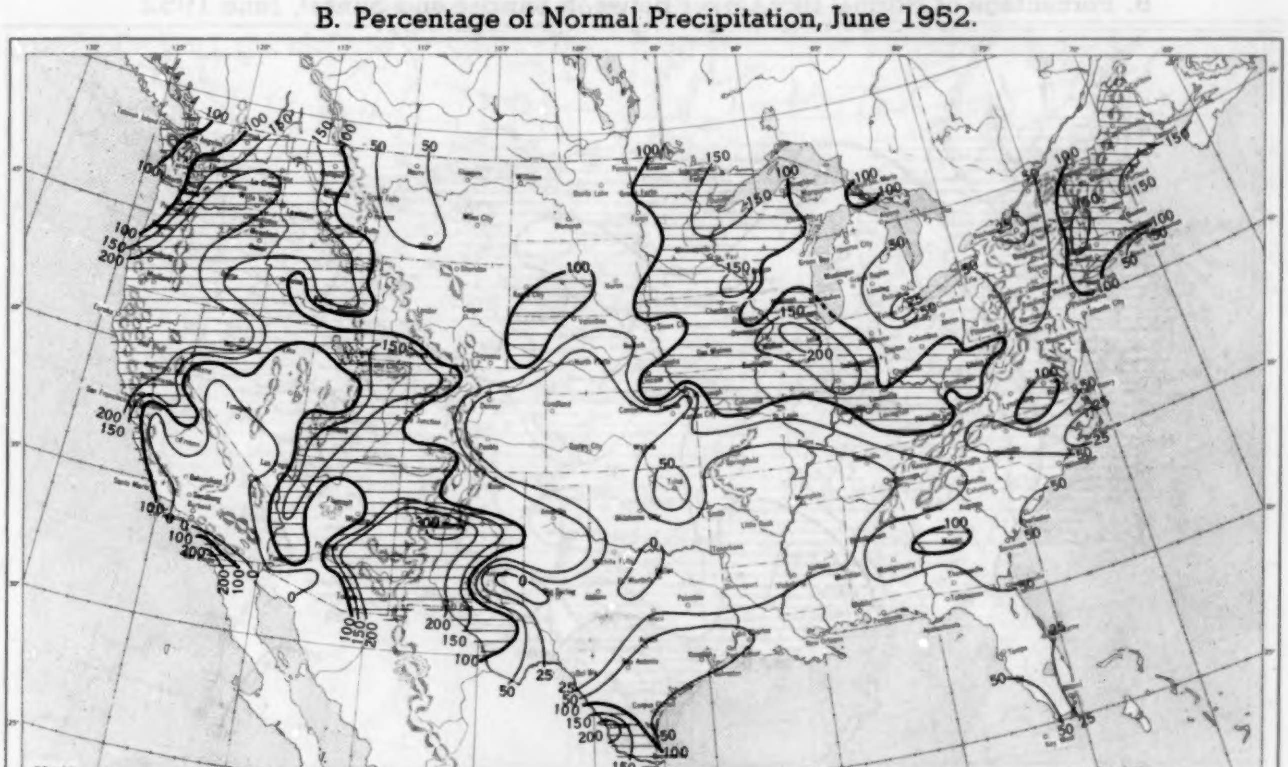
Chart II. Total Precipitation (Inches), June 1952.

Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), June 1952.

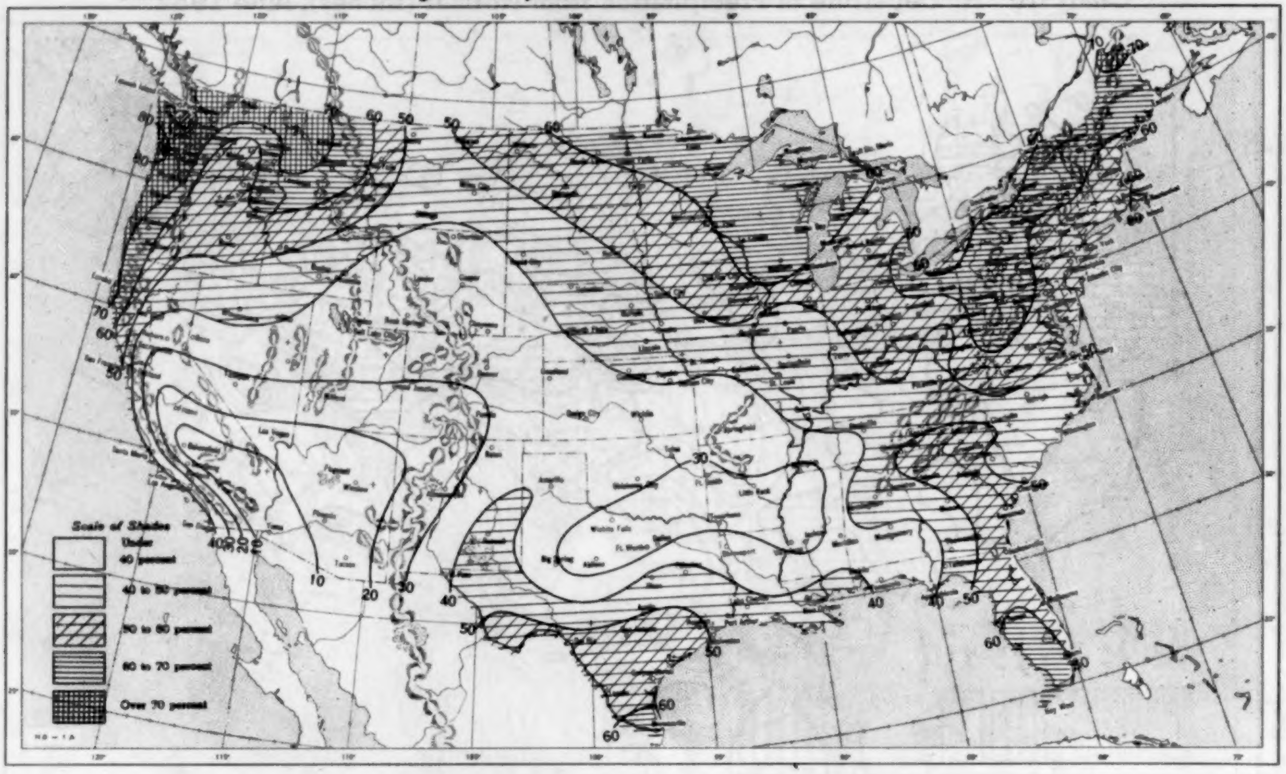


B. Percentage of Normal Precipitation, June 1952.

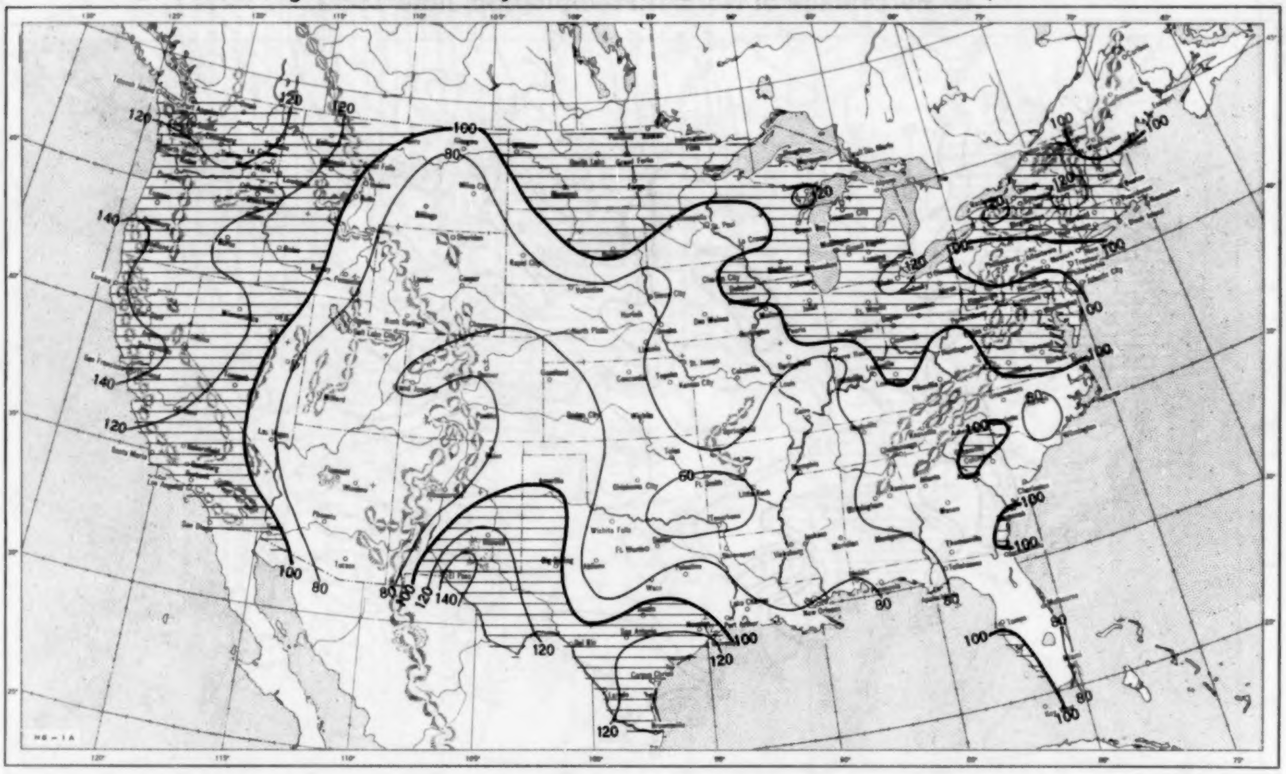


Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, June 1952.

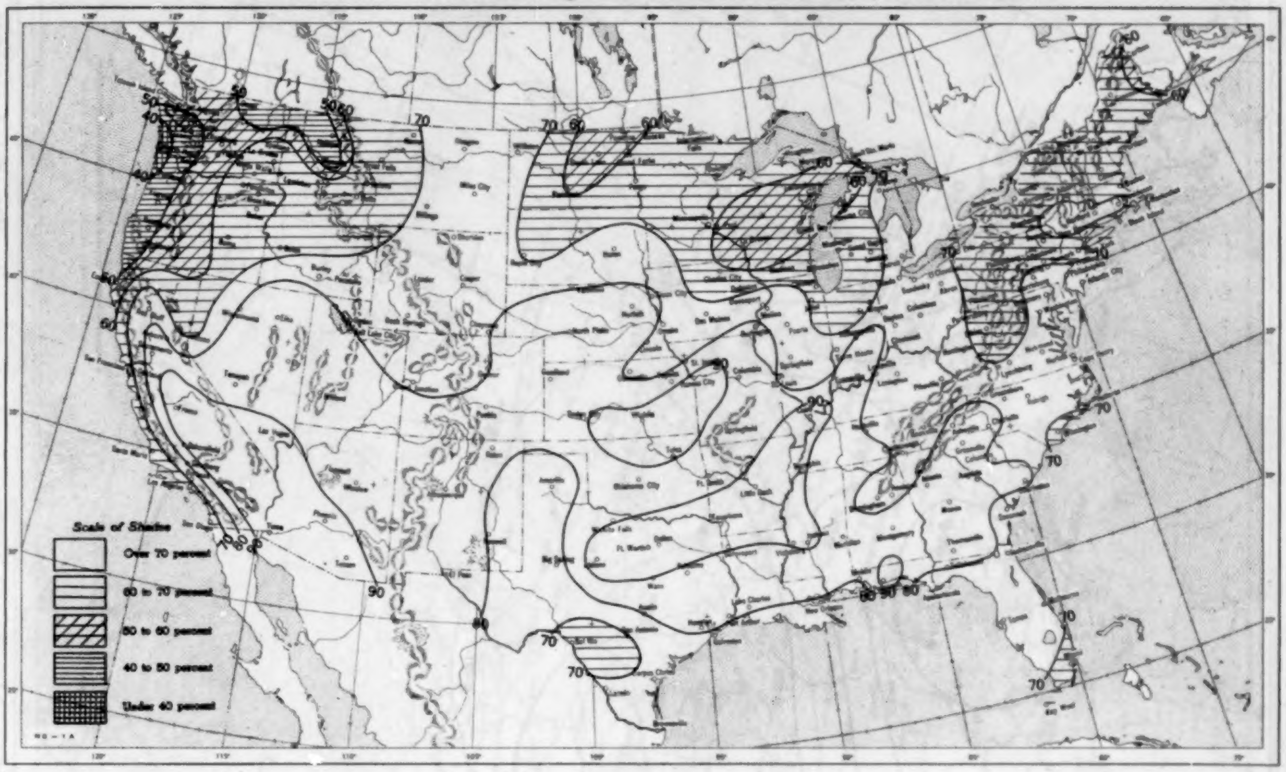


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, June 1952.

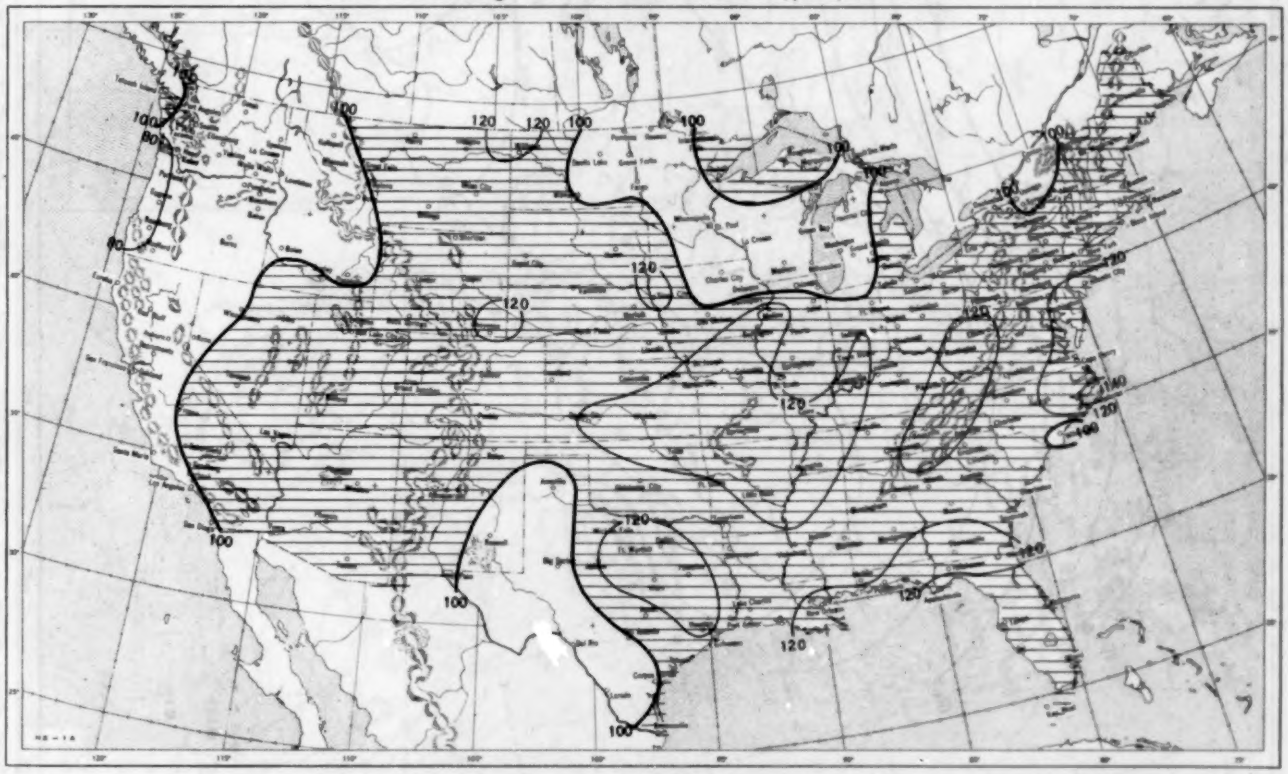


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, June 1952.



B. Percentage of Normal Sunshine, June 1952.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, June 1952. Inset: Percentage of Normal Average Daily Solar Radiation, June 1952.

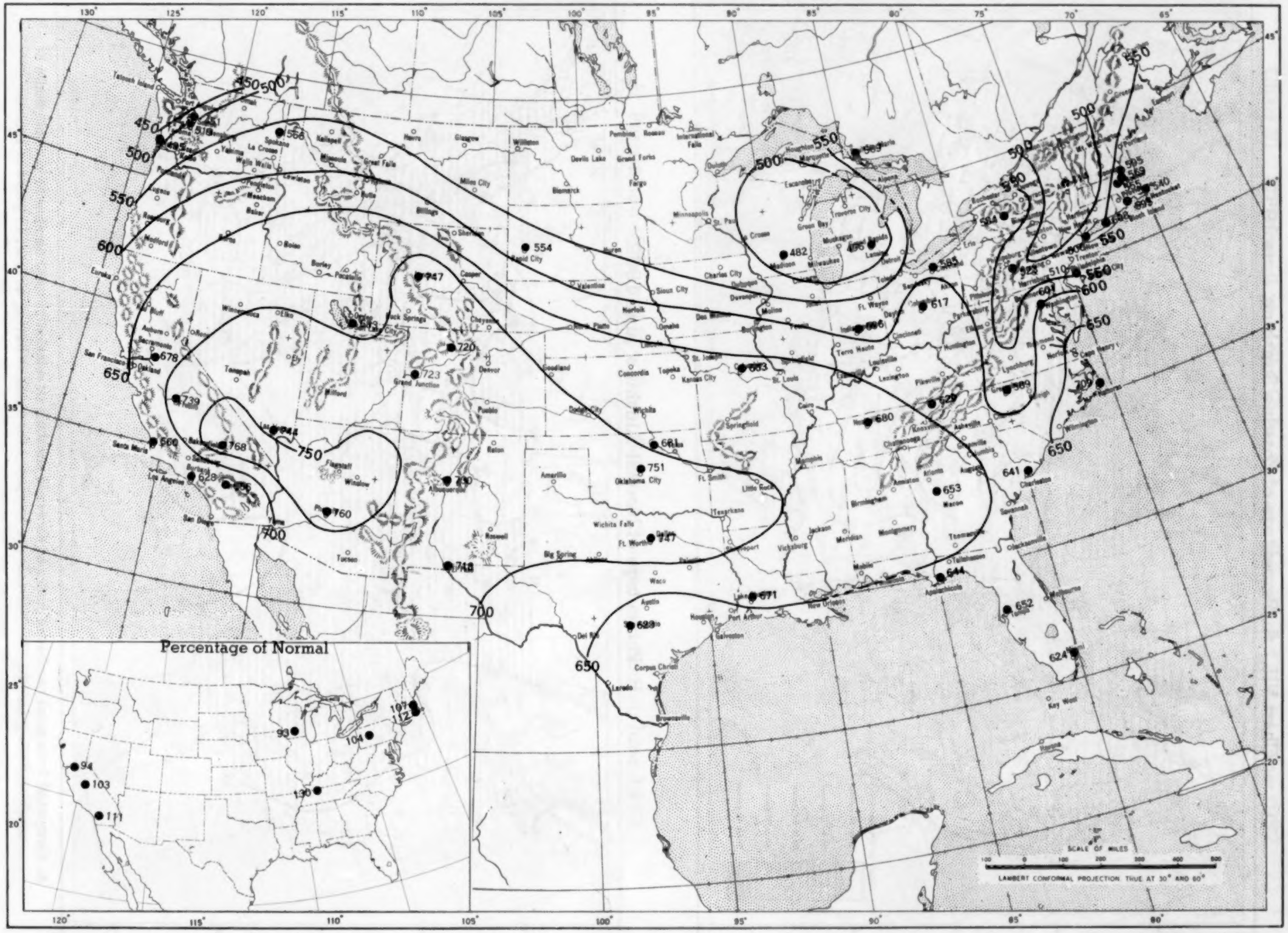
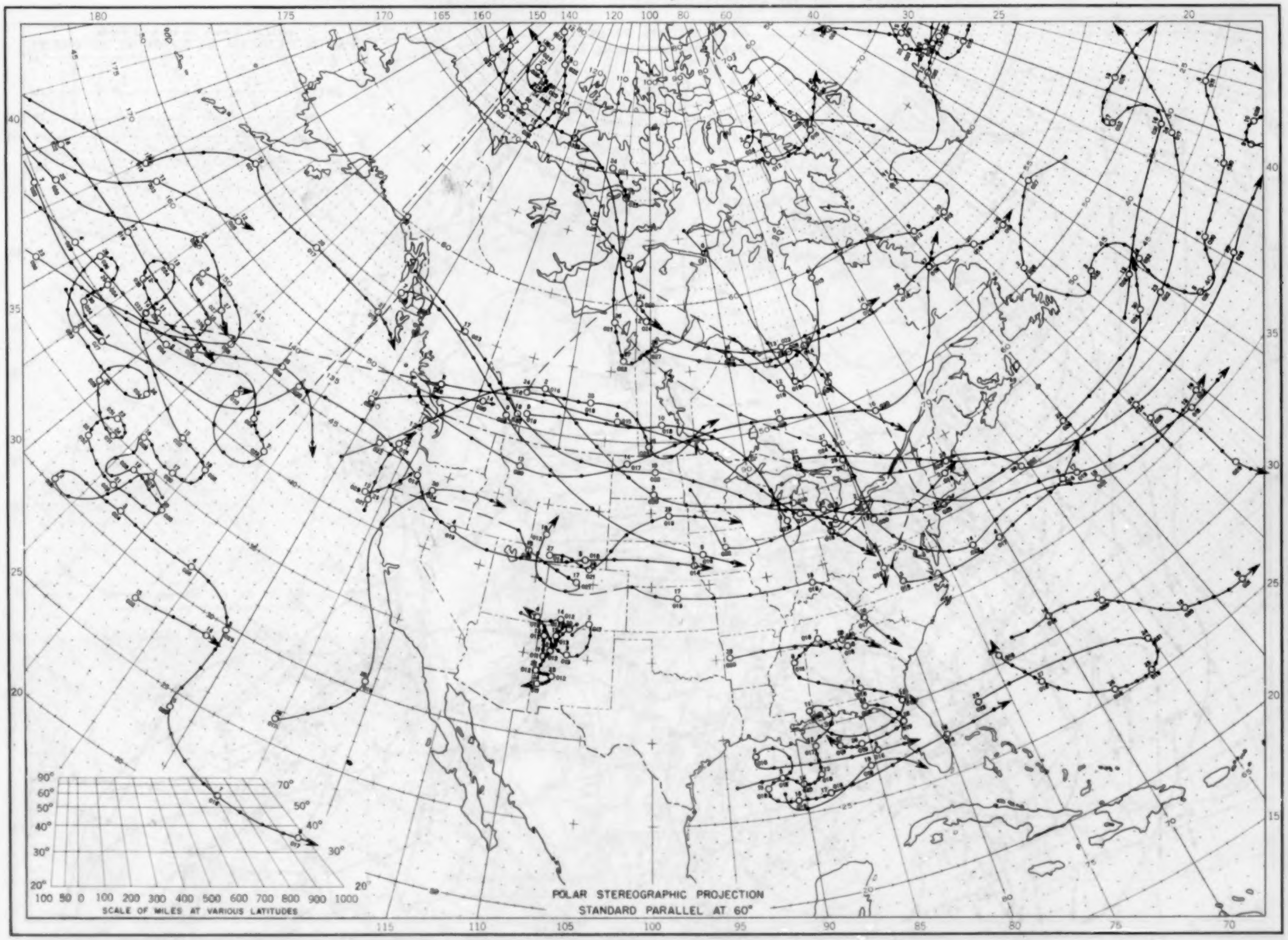


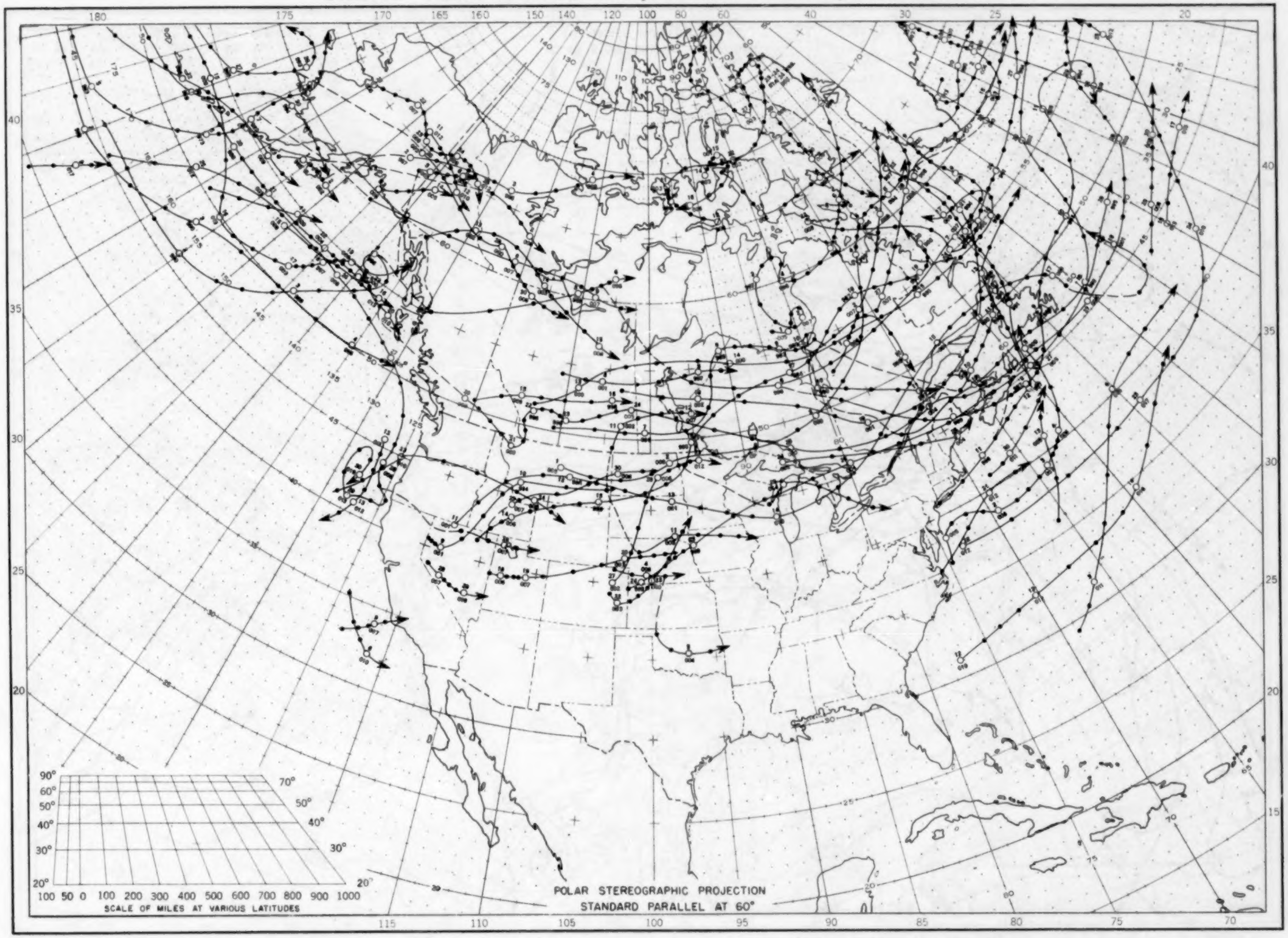
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm.$^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown. Normals are computed for stations having at least 9 years of record.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, June 1952.



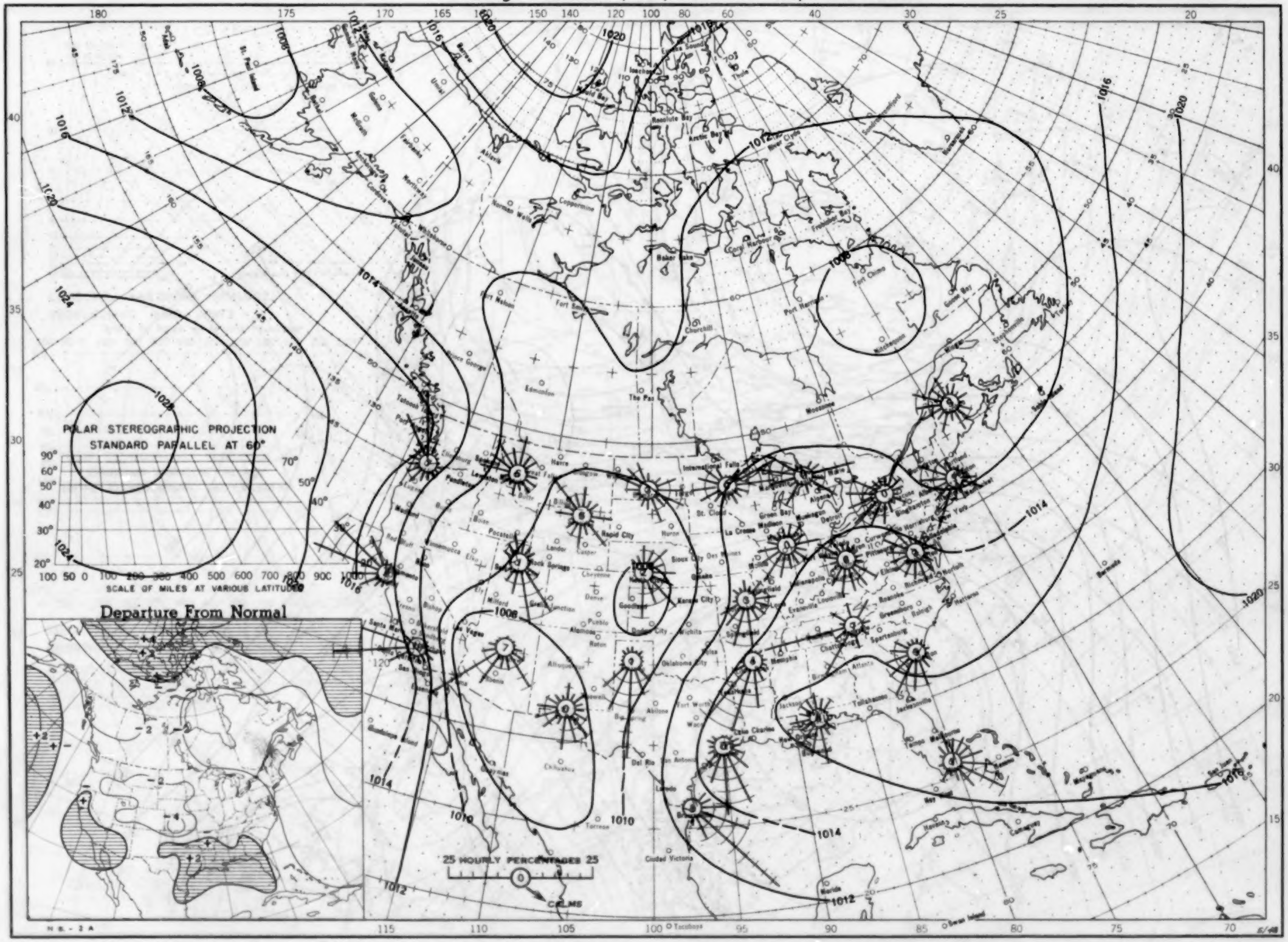
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, June 1952.



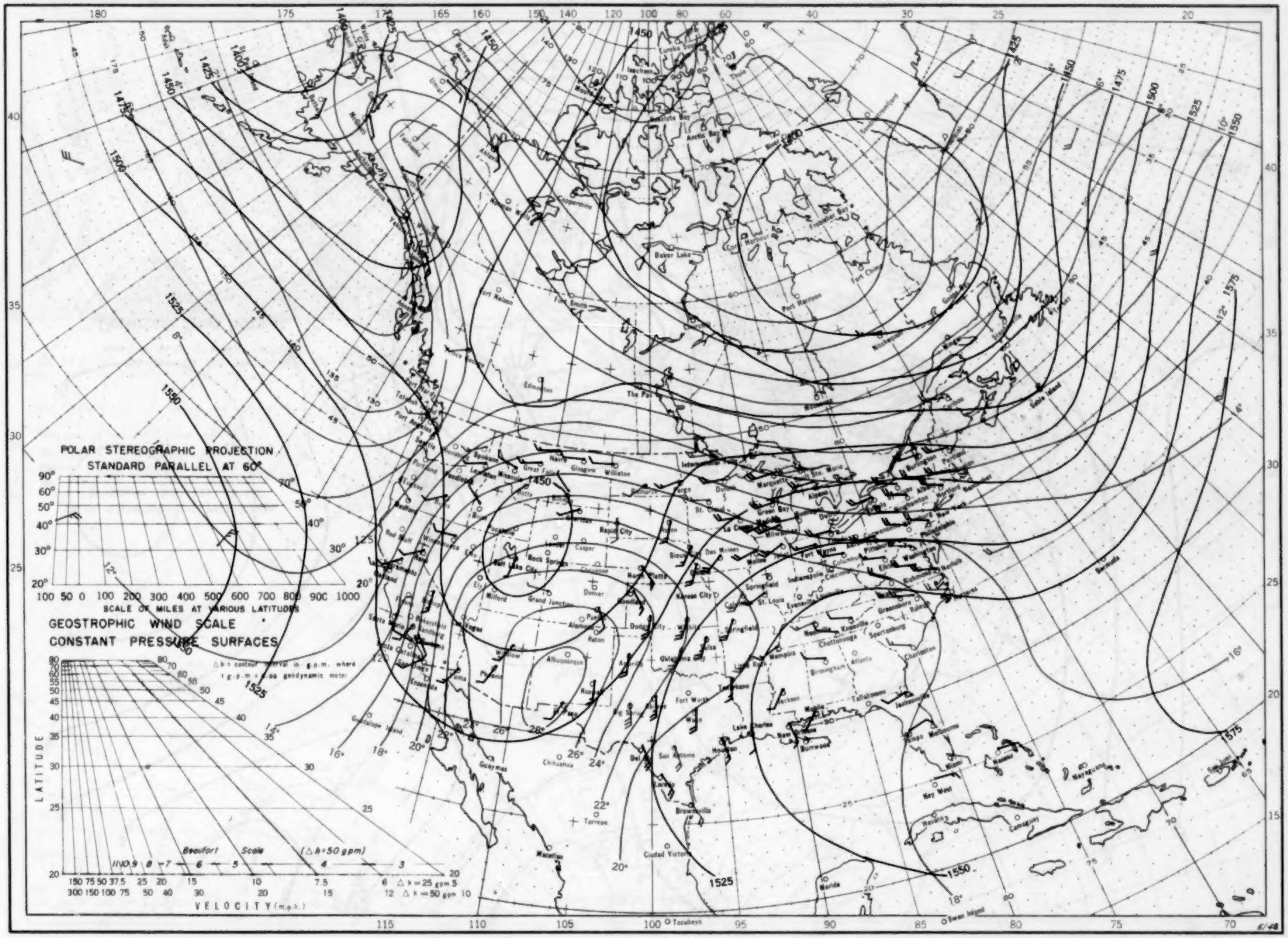
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, June 1952. Inset: Departure of Average Pressure (mb.) from Normal, June 1952.



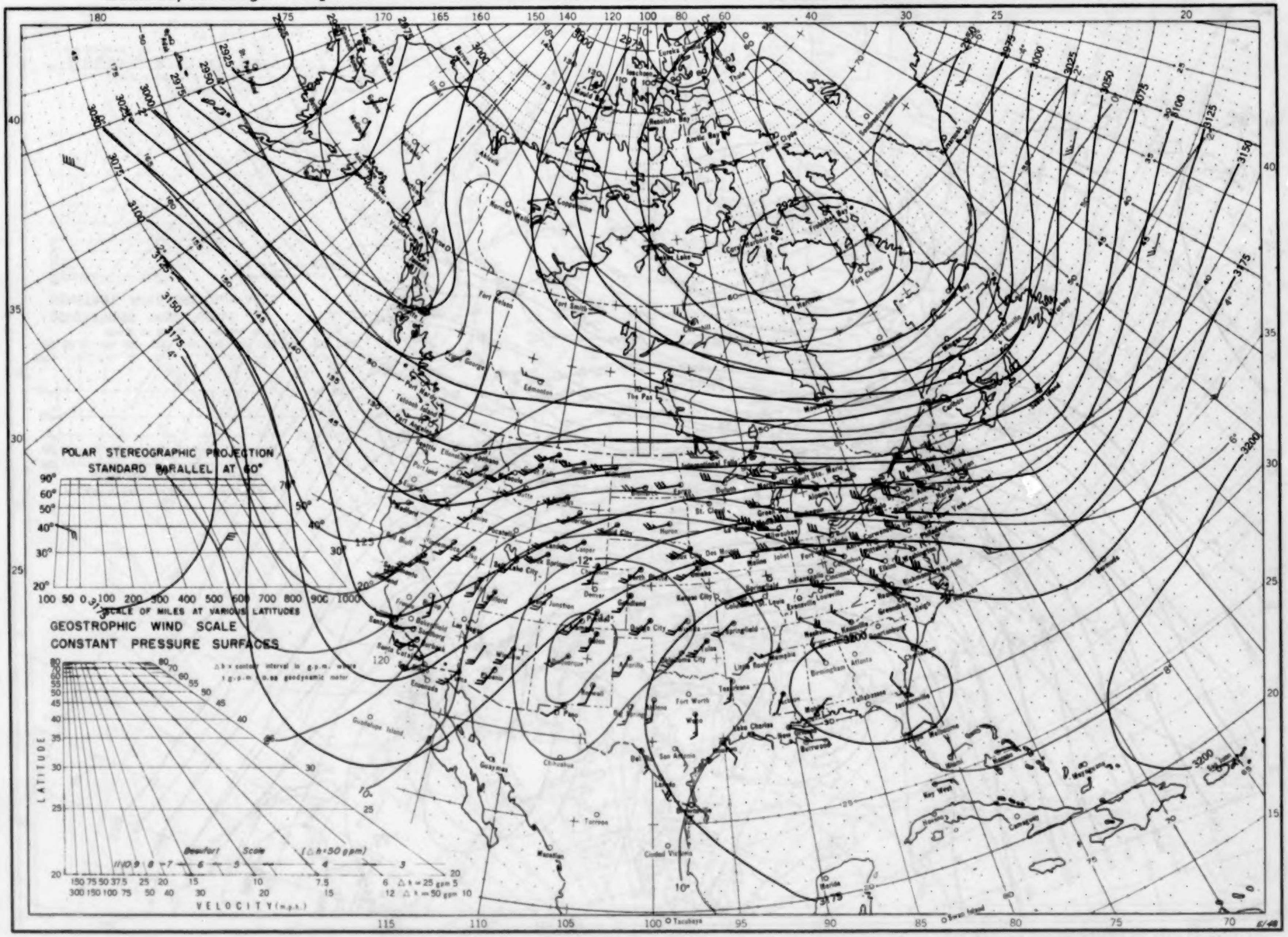
Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), June 1952.



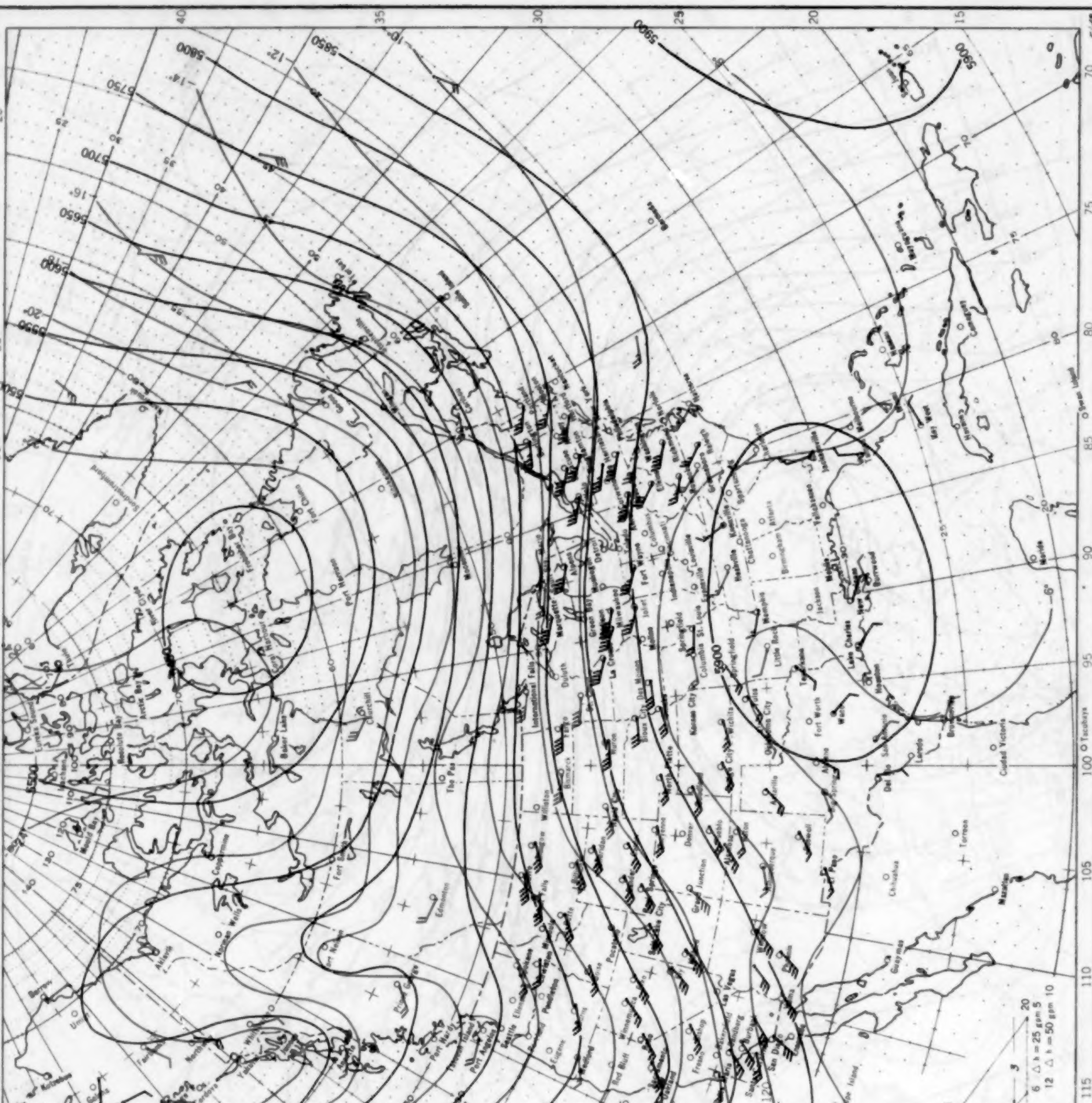
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m.. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), June 1952.



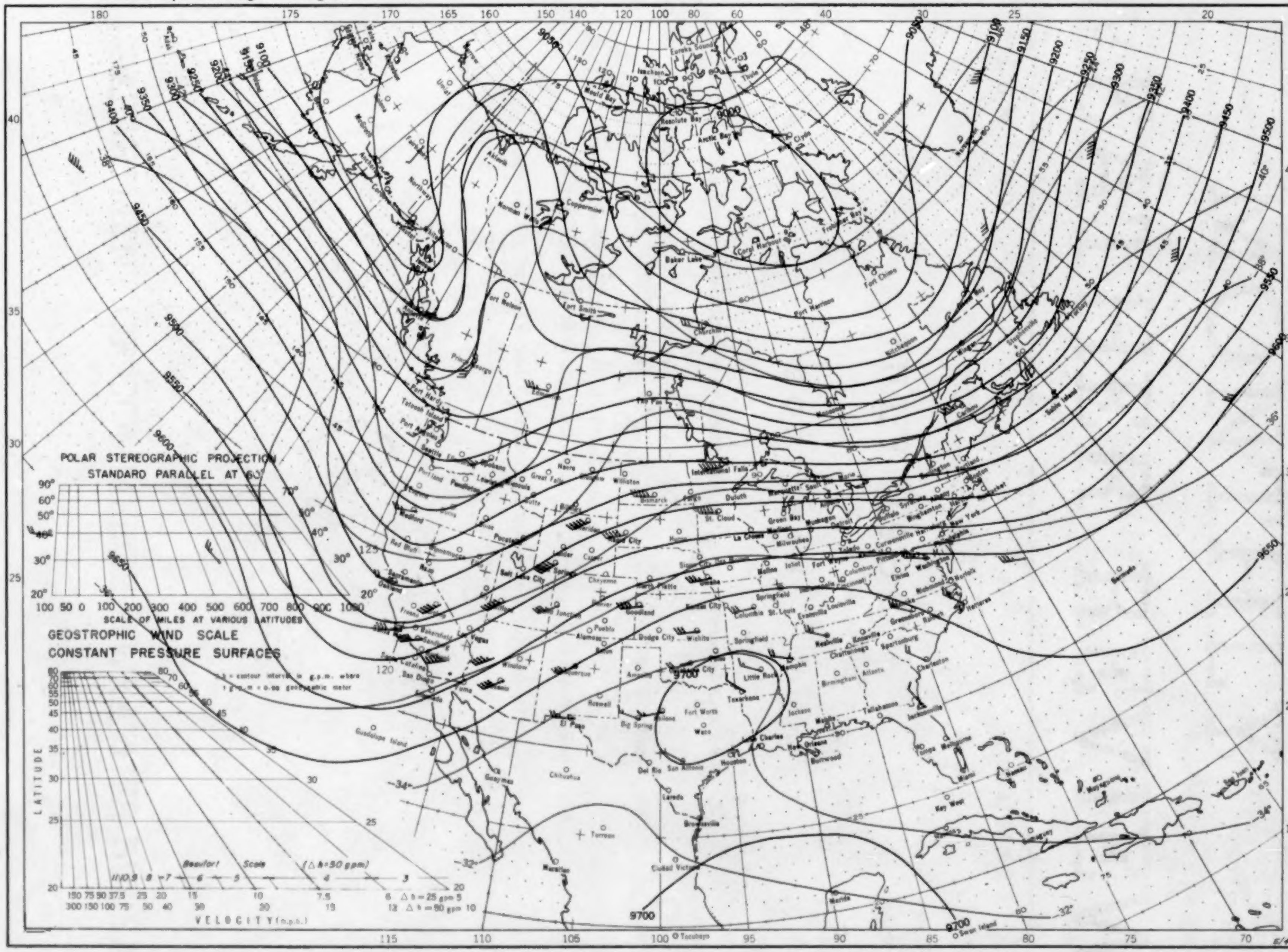
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), June 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), June 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.